7N-20
198734
P-74

NASA TN D-275

TECHNICAL NOTE

D-275

COMPILATION OF THERMODYNAMIC PROPERTIES, TRANSPORT PROPERTIES, AND THEORETICAL ROCKET PERFORMANCE OF GASEOUS HYDROGEN

By Charles R. King

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON April 1960

(NASA-TN-D-275) COMPILATION OF THERMODYNAMIC PROPERTIES, TRANSPORT PROPERTIES AND THEORETICAL ROCKET PERFORMANCE OF GASEOUS HYDROGEN (NASA) 74 p

N89-70412

Unclas
00/20 0198734

1L

E-692

CT-1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-275

COMPILATION OF THERMODYNAMIC PROPERTIES, TRANSPORT PROPERTIES, AND THEORETICAL ROCKET PERFORMANCE OF GASEOUS HYDROGEN

By Charles R. King

SUMMARY

Thermodynamic properties, transport properties, and theoretical performance for equilibrium composition during an isentropic expansion were computed for normal hydrogen as a rocket propellant. Data are presented for chamber temperatures from 600° to 5000° K, chamber pressures from 0.146960 to 1469.60 pounds per square inch absolute, and nozzle pressure ratios from 1 to 3000.

Properties and performance parameters computed include: nozzle-exit pressure, nozzle-exit temperature, enthalpy, molecular weight, isentropic exponent, specific heat at constant pressure, absolute viscosity, thermal conductivity, Mach number, specific impulse in vacuum, ratio of nozzle-exit area to throat area, thrust coefficient, specific impulse, equilibrium gas composition, characteristic velocity, and entropy. Additional data were compiled and are presented in the form of curves to show some of the properties of normal hydrogen, orthohydrogen, and parahydrogen at low temperatures for several pressures. These figures include computed data as well as data taken from available literature.

INTRODUCTION

In recent years there has been an increasing interest in the use of hydrogen as a propellant for rocket propulsion systems. Before accurate design studies and performance calculations can be made for these systems, it is necessary to know the thermodynamic properties, the transport properties, and the theoretical performance of the proposed propellant - hydrogen. It is necessary to know these properties over the entire range of powerplant operating temperatures and pressures. Although there is a considerable amount of information in the literature on the properties of hydrogen (refs. 1 to 16), this information does not always cover the entire range of conditions of interest. Furthermore, the literature usually

presents data on normal hydrogen. Design studies and performance calculations for powerplants currently of interest require data on the properties of parahydrogen and of mixtures of parahydrogen and orthohydrogen at low temperatures. Of greater importance is the need to know the properties of hydrogen in the region where hydrogen dissociates.

Data have been compiled at the Lewis Research Center to provide the required property data for hydrogen for a wider range of temperatures and pressures than were heretofore available, including temperatures and pressures where hydrogen becomes dissociated. In addition, rocket performance calculations have been made using hydrogen as the propellant and assuming equilibrium composition during an isentropic expansion through the exhaust nozzle. These calculations are based on the latest thermodynamic data available and were carried out in accordance with the methods described in references 4 and 17 as programmed in reference 17 for use with a high-speed data-processing machine. In addition to the equilibrium gas composition for assigned values of chamber temperature and pressure, the program calculates nozzle-exit pressure, nozzle-exit temperature, enthalpy, molecular weight, isentropic exponent, specific heat at constant pressure, absolute viscosity, thermal conductivity, Mach number, specific impulse in vacuum, ratio of nozzle-exit area to throat area, thrust coefficient, specific impulse, characteristic velocity, and entropy.

The data are presented in tables and figures for temperatures from 600° to 5000° K for chamber pressures of 0.146960 to 1469.60 pounds per square inch absolute and exhaust-nozzle pressure ratios from 1 to 3000. Additional data were compiled and are presented in the form of curves to show some of the properties of normal hydrogen, orthohydrogen, and parahydrogen at low temperatures for several pressures. These figures include computed data as well as data taken from available literature.

SYMBOLS

A	nozzle cross-sectional area, sq in.
$b\rho x$	parameter (ref. 2)
C_F	coefficient of thrust, $C_F = g_c I/c^* = F/P_c A_t$
c^*	characteristic velocity, $g_c P_c A_t/w$
c_p	specific heat at constant pressure, $(\partial h/\partial T)_P$, cal/(g)($^{\circ}$K)
c_p°	ideal specific heat at constant pressure, $(\partial h/\partial T)_P$, cal/(g)($^{\circ}$K)
c_v	specific heat at constant volume, cal/(g)($^{\circ}$K)

E-692

CT-1 back

c_v^o	ideal specific heat at constant volume, cal/(g)(^oK)
F	thrust, lb
F^o	molar free energy at standard conditions, cal/mole
$f_\mu^{(k)}$	function of force constant ϵ/k and temperature T
g_c	gravitational conversion factor, 32.174 (lb mass/lb force) (ft/sec^2)
H_T^o	sum of sensible enthalpy and base enthalpy (67,416.9 cal/mole) at 0° K, cal/mole
h	sum of sensible enthalpy and base enthalpy (33,440.9 cal/g) at 0° K, $\frac{\sum_i x_i (H_T^o)_i}{\mathcal{M}}$, cal/g
I	specific impulse with ambient and exit pressures equal, (lb thrust)/(lb propellant)/sec
I_{vac}	specific impulse in vacuum, I + P(A/w), (lb thrust)/(lb propellant)/sec
k	coefficient of thermal conductivity, cal/(sec)(cm)(^oK)
M	Mach number
$\mathcal{M}$	molecular weight, $\sum_i x_i \mathcal{M}_i$, g/g-mole or lb/lb-mole
P	static pressure (sum of partial pressures), lb/sq in.
p	partial pressure, lb/sq in.
R	universal gas constant, consistent units
S	entropy (does not include nuclear spin), cal/(gm)(^oK)
$\overline{S}$	entropy, 2.016 S, cal/(mole H_2)(^oK)
S_T^o	entropy at standard conditions, cal/(mole)(^oK)
T	temperature, ^oK

w	mass-flow rate, (lb mass)/sec
x	mole fraction
γ	ratio of specific heats, c_p/c_v
ϵ	ratio of nozzle area to throat area, A/A_t
ϵ/k	force constants for viscosity calculation, $^{\circ}K$
κ	isentropic exponent, $\frac{c_p}{c_v}\left[1 + \left(\frac{\partial \ln \mathscr{M}}{\partial \ln P}\right)_T\right]^{-1}$
μ	absolute viscosity, g/(cm)(sec)
σ	collision diameter for viscosity calculation, A
$\Omega^{(2,2)*}$	function of force constant ϵ/k and temperature T

Subscripts:

c	chamber
H	atomic hydrogen
H_2	molecular hydrogen
i	i^{th} substance
n	normal hydrogen, 75 percent orthohydrogen and 25 percent parahydrogen
o	orthohydrogen
p	parahydrogen
t	throat
1	reference point

CALCULATION PROCEDURE

General Method

The calculation of the propellant properties and the theoretical performance of a rocket using hydrogen as the working fluid is complicated

E-692

by the fact that hydrogen dissociates at high temperatures. Nevertheless, the equilibrium composition and a few of the properties of the dissociated hydrogen are easily computed from equations for chemical equilibrium and Dalton's law of partial pressure, providing the temperature and the pressure of the gas are known. For a process such as an isentropic expansion to an assigned pressure in an exhaust nozzle, the temperature and pressure are not known when there is dissociation or recombination taking place in the stream. However, an isentropic expansion process can be described by the addition of equations for the conservation of mass and entropy. The resulting equations are as follows:

$$\frac{\Delta F^{o}}{RT} = \ln p_{H_2} - \ln p_H \tag{1}$$

$$\frac{\overline{S}}{R} = \left(\frac{S_T^{o}}{R} - \ln p\right)_H \frac{2p_H}{\left(2p_{H_2} + p_H\right)} + \left(\frac{S_T^{o}}{R} - \ln p\right)_{H_2} \frac{2p_{H_2}}{\left(2p_{H_2} + p_H\right)} \tag{2}$$

These equations are algebraic nonlinear equations and can be solved by an iterative technique such as the one described in references 4 and 17. This technique has been programmed in reference 17 for use with a high-speed computing machine. The data presented herein in tables were computed using this program. This program was written primarily for the purpose of computing the performance of chemical rockets where many reaction products are present; therefore, it was necessary to simplify the program in order to compute the performance of a heat-transfer-type rocket using hydrogen alone as the propellant. Further, the computation of the equilibrium combustion temperature was omitted. Instead, the equilibrium composition and theoretical rocket performance were computed for assigned chamber temperatures. (The successive approximation process used in the calculation procedure was continued until seven-figure accuracy was reached in the desired values of the assigned parameters.) The equations in the program (ref. 17) for computing the various performance parameters were derived from the one-dimensional forms of the continuity, energy, and momentum equations using the following assumptions:

(1) zero velocity in the chamber

(2) perfect gas law

(3) homogeneous mixing

(4) isentropic expansion

These equations are given in reference 17 and in texts on rocket propulsion such as references 18 and 19.

269-E

A second program (unpublished) for computing viscosity and thermal conductivity in conjunction with the program described in reference 17 is in existence at the Lewis Research Center and was used to compute the transport properties.

Thermodynamic Data

The program described in reference 17 and used herein solves for temperature simultaneously with composition. For this reason, it was necessary to represent the specific heat, enthalpy, and entropy data for each constituent as functions of temperature. These properties were obtained by a least-squares fit of the thermodynamic data presented in reference 1 and were represented by power series equations. The resulting equations and the coefficients for atomic and molecular hydrogen are tabulated in reference 17.

Transport Properties

A second program (unpublished) for computing viscosity and thermal conductivity in conjunction with the program presented in reference 17 is in existence at the Lewis Research Center. The equations used in this program were simplified because of machine storage limitations in order to handle the many reaction products in a chemical rocket. More exact equations (ref. 20) could be used to compute the viscosity and thermal conductivity of hydrogen; however, no changes were made in the existing program for the calculation of the viscosity and thermal conductivity of hydrogen presented herein.

Viscosity. - Viscosity data are needed in making heat-transfer and flow studies. Calculations have been made to determine the viscosity of hydrogen for the range of conditions included in this report. The simplified equation used herein in order to make use of an existing program is based on averaging the kinematic viscosities of the atomic and molecular hydrogen. This equation gives values for viscosity that are often sufficiently accurate for engineering purposes and is as follows:

$$\mu = \frac{\mathcal{M}}{\sum_i \frac{x_i \mathcal{M}_i}{\mu_i}} \tag{3}$$

This equation seems reasonable in the absence of experimental viscosity data for the individual constituents at high temperatures.

The viscosities of the individual constituents in equation (3) were computed using the following equation (ref. 20):

$$\mu \times 10^7 = \frac{266.93\sqrt{\mathcal{M}T}\, f_\mu^{(k)}}{\sigma^2 \Omega^{(2,2)*}} \tag{4}$$

where the parameters $\Omega^{(2,2)*}$ and $f_\mu^{(k)}$ can be obtained from reference 20 as functions of the force constants ϵ/k and temperature. The force constants ϵ/k and σ for atomic and molecular hydrogen were calculated from experimental viscosity data. The resulting values of these parameters appear in reference 21 and are given in the following table:

Substance	σ, A	ϵ/k, $^{\circ}$K
H	2.497	99.8
H_2	2.729	86.1

Thermal conductivity. - Thermal conductivity data as well as viscosity data are needed for heat-transfer calculations. However, experimental conductivity data are generally even less available than experimental viscosity data. The Eucken relation used herein in order to make use of an existing program is as follows:

$$k = \mu\left(c_p + \frac{5}{4}\frac{R}{\mathcal{M}}\right) \tag{5}$$

This relation often gives satisfactory values of conductivity for individual components and is used in this report to estimate the conductivity of the gaseous mixtures of atomic and molecular hydrogen.

Ortho-Parahydrogen Properties

Hydrogen gas can be considered as a mixture of two distinct components, orthohydrogen and parahydrogen (ref. 2). The higher temperature (above 600° K) equilibrium mixture of the two forms is called normal hydrogen. The normal mixture of hydrogen is made up of 75 percent orthohydrogen and 25 percent parahydrogen. The properties and performance data presented herein for temperatures above 600° K are for normal hydrogen and were computed by the method of reference 17 as discussed previously. At lower temperatures the equilibrium mixture can vary depending upon such factors as the method of manufacture, the time in storage, and the presence of a catalyst. Since the properties of orthohydrogen and parahydrogen are different, it is necessary to know the composition of the hydrogen at temperatures below 600° K before it is possible to determine the properties of the mixture. Some of the properties of orthohydrogen and parahydrogen are presented in figures herein for temperatures

below 600° K and several pressures. These properties were obtained from available literature or were computed as follows:

Specific heat. - The ideal specific heats at constant pressure for orthohydrogen, normal hydrogen, and parahydrogen were obtained from reference 2. The specific heats of normal hydrogen for higher pressures were obtained from reference 1. Reference 2 suggests that the specific heat at constant pressure for orthohydrogen and parahydrogen at high pressures can be computed using the real-gas corrections for normal hydrogen in the following equations:

$$c_{p,o} = c_{p,o}^{o} + \left(c_{p,n} - c_{p,n}^{o}\right) \tag{6}$$

$$c_{p,p} = c_{p,p}^{o} + \left(c_{p,n} - c_{p,n}^{o}\right) \tag{7}$$

The real-gas correction term $\left(c_{p,n} - c_{p,n}^{o}\right)$ can be computed from the data in reference 1 or from equation (5.8) in reference 2. The various parameters required in the solution of equation (5.8) are given in tables in reference 2.

Ratio of specific heats. - The ratio of ideal specific heats of normal hydrogen for several pressures was obtained from reference 1. To obtain the ratios of ideal specific heats for orthohydrogen and parahydrogen, it was necessary to compute the ideal specific heat at constant volume using the ideal specific heats at constant pressure given in reference 2 and the following equations:

$$c_v^{o} = c_p^{o} - \frac{R}{\mathcal{M}} \tag{8}$$

and

$$\gamma = \frac{c_p^{o}}{c_v^{o}} \tag{9}$$

The ideal specific heat at constant volume will be used in succeeding calculations.

The following equations were used to calculate the specific heat at constant volume at high pressures:

$$c_{v,o} = c_{v,o}^{o} + \left(c_{v,n} - c_{v,n}^{o}\right) \tag{10}$$

$$c_{v,p} = c_{v,p}^{o} + \left(c_{v,n} - c_{v,n}^{o}\right) \tag{11}$$

The real-gas correction term $\left(c_{v,n} - c_{v,n}^{o}\right)$ was calculated from equation (5.7) in reference 2. The various parameters required in the solution of equation (5.7) are given in tables in reference 2. The ratio of specific heats of orthohydrogen and parahydrogen for several pressures was obtained by combining the data of equations (6) and (10) and (7) and (11) in equation (9).

E-692

Viscosity. - From experimental work presented in reference 22 and described in reference 3, it is concluded that there is no difference in the viscosities of normal hydrogen, orthohydrogen, and parahydrogen. The viscosity data presented herein for a pressure of 14.6960 pounds per square inch absolute were obtained from references 2 and 13. Equation (6.17) (ref. 2), which was used herein to determine the magnitude of the effect of pressure on the viscosity of hydrogen, is as follows:

$$\frac{\mu}{\mu_1} = 1 + 0.175(b\rho x) + 0.7557(b\rho x)^2 - 0.405(b\rho x)^3 \tag{12}$$

CT-2

Equation (6.17) developed in reference 2 is based on a theoretical formula proposed by Enskog. The parameter $b\rho x$ required for the solution of equation (12) can be obtained from data presented in reference 2.

Thermal conductivity. - The thermal conductivity of normal-hydrogen gas at temperatures below 600° K can be found in many references, and these data agree fairly well. Thermal conductivity data for parahydrogen can be found in a few references. On the other hand, the thermal conductivity of orthohydrogen is generally not available. The data presented herein for normal hydrogen for a pressure of 14.6960 pounds per square inch absolute were obtained from reference 1. The data presented for higher pressures were computed from equation (6.18) in reference 2:

$$\frac{k}{k_1} = 1 + 0.575(b\rho x) + 0.5017(b\rho x)^2 - 0.204(b\rho x)^3 \tag{13}$$

This equation developed in reference 2 is based on a theoretical formula proposed by Enskog. The parameter $b\rho x$ required for the solution of equation (13) can be obtained from data presented in reference 2. The thermal conductivities for orthohydrogen and parahydrogen were computed by a method suggested in reference 3 using the Eucken relation as follows:

$$k_o = k_n \frac{\left(c_{p,n} + \frac{5}{4}\frac{R}{\mathscr{M}}\right)}{\left(c_{p,o} + \frac{5}{4}\frac{R}{\mathscr{M}}\right)} \tag{14}$$

and

$$k_p = k_n \frac{\left(c_{p,n} + \frac{5}{4}\frac{R}{\mathcal{M}}\right)}{\left(c_{p,p} + \frac{5}{4}\frac{R}{\mathcal{M}}\right)} \tag{15}$$

PRESENTATION OF RESULTS

The calculated values of the various performance parameters and the properties of hydrogen for chamber temperatures from 600° to 5000° K, chamber pressures from 0.146960 to 1469.60 pounds per square inch absolute, and exhaust-nozzle pressure ratios from 1 to 3000 are given in tables I to III. Typical variations in some of the data presented in tables I to III for temperatures above 600° K are presented in figures 1 to 13. These figures include computed data as well as data taken from available literature. The data in the figures for temperatures below 600° K are not tabulated.

Thermodynamic properties, transport properties, and performance parameters are presented in table I. The equilibrium composition of the gaseous hydrogen at the assigned temperatures and pressures is presented in table II. Characteristic velocity and entropy for the assigned temperatures and pressures are given in table III.

Thermodynamic and Transport Properties

The enthalpy, molecular weight, isentropic exponent, specific heat at constant pressure, absolute viscosity, and thermal conductivity of hydrogen are presented in table I. The entropy of hydrogen is given in table III. Properties for chamber conditions are found in the tables where the pressure ratio equals one ($P_c/P = 1$). Properties at the nozzle throat are found in the tables where the area ratio equals one ($\epsilon = 1$).

Specific heat at constant pressure, ratio of specific heats, enthalpy, and entropy of the gaseous hydrogen are presented in figures 1 to 6, respectively. The transport properties, absolute viscosity and thermal conductivity, are presented in figures 7 to 10, respectively. The molecular weight of the dissociated hydrogen at the assigned chamber temperatures and pressures is presented in figure 11.

The data presented in the figures for temperatures above 600° K were plotted from the tables presented herein. Data which do not appear in the tables have been included in figures 1, 3, 5(a), 7, and 9 and show some of the properties of normal orthohydrogen, parahydrogen, and normal

hydrogen at temperatures below 600° K for several pressures. These data were obtained by methods described in the section entitled CALCULATION PROCEDURE.

Theoretical Rocket Performance

Mach number, specific impulse, area ratio, thrust coefficient, and specific impulse in vacuum are presented in table I at assigned pressure ratios for each chamber temperature and pressure.

Typical plots of specific impulse in vacuum and area ratio for a pressure ratio of 1000 are presented in figures 12 and 13, respectively. These data were obtained from table I.

Figure 12(b) indicates that for each temperature above 3600° K there is only one particular chamber pressure that will produce the highest specific impulse in vacuum. Any additional reduction in the chamber pressure will reduce the specific impulse. At the lower pressures the loss of energy due to incomplete recombination in the exhaust nozzle becomes greater than the gain in energy by dissociation in the chamber.

Lewis Research Center,
National Aeronautics and Space Administration
Cleveland, Ohio, January 12, 1960

E-692

CT-2 back

REFERENCES

1. Hilsenrath, Joseph, et al.: Tables of Thermal Properties of Gases. Cir. 564, NBS, Nov. 1, 1955.

2. Woolley, Harold W., Scott, Russell B., and Brickwedde, F. G.: Compilation of Thermal Properties of Hydrogen in Its Various Isotopic and Ortho-Para Modifications. Jour. Res. Nat. Bur. Standards, vol. 41, no. 5, Nov. 1948, pp. 379-475.

3. Farkas, Adalbert: Orthohydrogen, Parahydrogen and Heavy Hydrogen. Cambridge Univ. Press, 1935.

4. Huff, Vearl N., Gordon, Sanford, and Morrell, Virginia E.: General Method and Thermodynamic Tables for Computation of Equilibrium Composition and Temperature of Chemical Reactions. NACA Rep. 1037, 1951. (Supersedes NACA TN's 2113 and 2161.)

5. Keyes, F. G.: A Summary of Viscosity and Heat Conduction Data for He, A, H_2, O_2, N_2, CO, CO_2, H_2O, and Air. Trans. ASME, vol. 73, no. 5, July 1951, pp. 589-596.

6. Keyes, Frederick G.: The Heat Conductivity, Viscosity, Specific Heat, and Prandtl Numbers for Thirteen Gases. Tech. Rep. 37, Prog. Squid, M.I.T., Apr. 1, 1952.

7. Bromley, LeRoy A.: Thermal Conductivity of Gases at Moderate Pressures. UCRL Rep. 1852, Radiation Lab., Univ. Calif., June 12, 1952. (Contract 7405-eng-48.)

8. Hilsenrath, Joseph, and Touloukian, Y. S.: The Viscosity, Thermal Conductivity, and Prandtl Number for Air, O_2, N_2, NO, H_2, CO, CO_2, H_2O, He and A. Trans. ASME, vol. 76, no. 6, Aug. 1954, pp. 967-985.

9. Hirschfelder, Joseph O., Bird, R. Byron, and Spotz, Ellen L.: The Transport Properties for Non-Polar Gases. Jour. Chem. Phys., vol. 16, no. 10, Oct. 1948, pp. 968-981.

10. Ellenwood, Frank O., Kulik, Nicholas, and Gay, Norman R.: The Specific Heats of Certain Gases Over Wide Ranges of Pressures and Temperatures. Bull. 30, Eng. Experiment Station, Cornell Univ., Oct. 1942.

11. Ring, I. H., and David, F. W.: Review of Available Data on the Heat Capacity of Some Common Gases. Tech. Note AERO 1846, S.D. 44, British RAE, Oct. 1946.

12. Johnston, Herrick L., and Grilly, Edward R.: The Thermal Conductivities of Eight Common Gases Between 80° and 380° K. Jour. Chem. Phys., vol. 14, no. 4, Apr. 1946, pp. 233-238.

13. Woolley, H. W.: Molecular Hydrogen. Table 7.39 of the NBS-NACA Tables of Thermal Properties of Gases, NBS, 1950.

14. Reisfeld, Martin J.: Thermodynamic and Transport Properties of Dissociated Hydrogen Mixtures. LA-2123, Los Alamos Sci. Lab., Univ. Calif., June 6, 1957.

15. Shipley, Kenneth L.: Tables of Isentropic Flow of Hydrogen Gas with Equilibrium Composition. SC-4265(TR), Sandia Corp., Dec. 1958.

16. Woolley, H. W.: Effect of Dissociation on Thermodynamic Properties of Pure Diatomic Gases. NACA TN 3270, 1955.

17. Gordon, Sanford, Zeleznik, Frank J., and Huff, Vearl N.: A General Method for Automatic Computation of Equilibrium Composition and Theoretical Rocket Performance of Propellants. NASA TN D-132, 1959.

18. Sutton, George P.: Rocket Propulsion Elements. Second ed., John Wiley & Sons, Inc., 1956.

19. Bussard, R. W., and DeLauer, R. D.: Nuclear Rocket Propulsion. McGraw-Hill Book Co., 1958.

20. Hirschfelder, Joseph D., Curtiss, Charles F., and Bird, R. Byron: Molecular Theory of Gases and Liquids. John Wiley & Sons, Inc., 1954.

21. Gordon, Sanford, and McBride, Bonnie J.: Theoretical Performance of Liquid Hydrogen with Liquid Oxygen as a Rocket Propellant. NASA MEMO 5-21-59E, 1959.

22. Harteck, P., and Schmidt, H. W.: Self-Diffusion of Hydrogen. Zs. f. Phys. Chem., Bd. 21, pt. B, 5-6, 1933, pp. 447-458.

E-692

TABLE I. - THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(a) Chamber temperature, 600° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(^\circ K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(^\circ K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific pulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	0.08	501	35144	2.016	1.3980	3.462	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	0.05	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	0.01	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	0.00	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.00	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.00	108	33835	2.016	1.5115	2.913	37	.0001	4.532	391.6	15.63	1.62	379.4
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	0.23	501	35144	2.016	1.3980	3.463	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	0.15	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	0.04	311	34490	2.016	1.4038	3.427	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	0.01	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.00	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.00	108	33835	2.016	1.5079	2.927	37	.0001	4.537	391.6	15.63	1.62	379.4
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	0.78	501	35144	2.016	1.3979	3.463	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	0.49	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	0.15	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	0.05	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.01	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.00	108	33835	2.016	1.5115	2.913	37	.0001	4.532	391.6	15.64	1.62	379.4
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	2.33	501	35144	2.016	1.3980	3.463	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	1.47	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	0.44	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	0.15	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.04	156	33977	2.016	1.4759	3.057	52	.0002	3.656	381.2	7.84	1.55	362.8
300.00	0.01	108	33835	2.016	1.5103	2.917	37	.0001	4.533	391.6	15.63	1.62	379.4
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	7.77	501	35144	2.016	1.3979	3.463	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	4.90	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	1.47	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	0.49	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.15	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.05	108	33835	2.016	1.5122	2.910	37	.0001	4.530	391.6	15.64	1.62	379.4
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	23.30	501	35144	2.016	1.3979	3.463	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	14.70	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	4.41	311	34490	2.016	1.4042	3.425	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	1.47	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	0.44	156	33977	2.016	1.4755	3.059	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.15	108	33835	2.016	1.5103	2.917	37	.0001	4.533	391.6	15.63	1.62	379.4
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	77.68	501	35144	2.016	1.3980	3.462	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	48.99	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	14.70	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	4.90	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	1.47	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	0.49	108	33835	2.016	1.5115	2.913	37	.0001	4.532	391.6	15.63	1.62	379.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	600	35489	2.016	1.3953	3.479	144	0.0006					
1.89	233.04	501	35144	2.016	1.3980	3.462	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	146.96	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	44.09	311	34490	2.016	1.4042	3.425	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	14.70	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.8
100.00	4.41	156	33977	2.016	1.4760	3.057	52	.0002	3.656	381.2	7.84	1.55	362.8
300.00	1.47	108	33835	2.016	1.5103	2.917	37	.0001	4.533	391.6	15.64	1.62	379.4
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	600	35489	2.016	1.3954	3.479	144	0.0006					
1.89	776.78	501	35144	2.016	1.3980	3.462	127	.0006	1.000	297.2	1.00	0.74	173.2
3.00	489.87	439	34931	2.016	1.3970	3.469	116	.0005	1.359	305.8	1.09	0.94	220.4
10.00	146.96	311	34490	2.016	1.4040	3.426	91	.0004	2.154	340.2	1.93	1.26	294.9
30.00	48.99	226	34201	2.016	1.4258	3.301	71	.0003	2.848	363.7	3.70	1.43	334.9
100.00	14.70	156	33977	2.016	1.4750	3.061	52	.0002	3.657	381.2	7.84	1.55	362.8
300.00	4.90	108	33835	2.016	1.5094	2.921	37	.0001	4.535	391.6	15.63	1.62	379.4

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(b) Chamber temperature, 1000° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	0.08	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	0.05	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	0.01	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	0.00	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.00	271	34352	2.016	1.4080	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	0.00	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.00	133	33908	2.016	1.4940	2.981	45	.0001	5.526	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	0.23	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	0.15	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	0.04	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	0.01	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.00	271	34352	2.016	1.4083	3.400	82	.0003	3.678	495.2	8.13	1.55	470.6
300.00	0.00	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.00	133	33908	2.016	1.4934	2.984	45	.0001	5.527	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	0.78	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	0.49	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	0.15	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	0.05	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.01	271	34352	2.016	1.4080	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	0.00	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.00	133	33908	2.016	1.4922	2.989	45	.0001	5.529	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	2.34	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	1.47	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	0.44	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	0.15	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.04	271	34352	2.016	1.4079	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	0.01	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.00	133	33908	2.016	1.4934	2.984	45	.0001	5.527	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	7.79	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	4.90	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	1.47	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	0.49	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.15	271	34352	2.016	1.4080	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	0.05	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.01	133	33908	2.016	1.4940	2.981	45	.0001	5.526	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	23.37	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	14.70	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	4.41	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	1.47	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	0.44	271	34352	2.016	1.4083	3.400	82	.0003	3.678	495.2	8.13	1.55	470.6
300.00	0.15	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.04	133	33908	2.016	1.4934	2.984	45	.0001	5.527	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	77.91	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	48.99	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	14.70	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	4.90	383	34736	2.016	1.3987	3.458	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	1.47	271	34352	2.016	1.4080	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	0.49	195	34101	2.016	1.4451	3.200	63	.0002	4.482	510.2	16.78	1.62	493.2
1000.00	0.15	133	33908	2.016	1.4922	2.989	45	.0001	5.529	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	233.73	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	146.96	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	44.09	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	14.70	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	4.41	271	34352	2.016	1.4083	3.400	82	.0003	3.678	495.2	8.13	1.55	470.6
300.00	1.47	195	34101	2.016	1.4444	3.204	63	.0002	4.484	510.2	16.78	1.62	493.2
1000.00	0.44	133	33908	2.016	1.4940	2.981	45	.0001	5.526	521.1	36.82	1.68	509.9
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	1000	36897	2.016	1.3800	3.580	201	0.0009					
1.89	779.10	838	36323	2.016	1.3882	3.525	179	.0008	1.000	384.4	1.00	0.74	223.4
3.00	489.87	736	35963	2.016	1.3926	3.496	165	.0007	1.359	395.7	1.09	0.94	285.0
10.00	146.96	523	35223	2.016	1.3974	3.467	131	.0006	2.155	440.4	1.93	1.26	381.6
30.00	48.99	383	34736	2.016	1.3988	3.457	106	.0005	2.861	471.4	3.74	1.43	433.6
100.00	14.70	271	34352	2.016	1.4080	3.402	82	.0003	3.679	495.2	8.13	1.55	470.6
300.00	4.90	195	34101	2.016	1.4445	3.203	63	.0002	4.483	510.2	16.78	1.62	493.2
1000.00	1.47	133	33908	2.016	1.4922	2.989	45	.0001	5.529	521.1	36.82	1.68	509.9

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(c) Chamber temperature, 1400° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	1400	38368	2.016	1.3512	3.796	250	0.0012					
1.87	0.08	1186	37569	2.016	1.3676	3.667	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	0.05	1044	37053	2.016	1.3772	3.599	206	.0010	1.363	470.6	1.09	0.94	338.3
10.00	0.01	746	36000	2.016	1.3922	3.499	166	.0007	2.150	524.5	1.95	1.26	454.0
30.00	0.00	547	35305	2.016	1.3956	3.471	135	.0006	2.852	561.7	3.77	1.43	516.3
100.00	0.00	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.4	8.22	1.55	560.7
300.00	0.00	283	34394	2.016	1.4057	3.415	85	.0003	4.499	608.7	17.15	1.63	588.0
1000.00	0.00	198	34111	2.016	1.4447	3.207	64	.0002	5.492	622.6	38.67	1.68	608.6
3000.00	0.00	140	33929	2.016	1.4879	3.004	47	.0002	6.578	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	1400	38368	2.016	1.3520	3.795	250	0.0012					
1.87	0.24	1186	37569	2.016	1.3676	3.667	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	0.15	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.6	1.09	0.94	338.3
10.00	0.04	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	0.01	547	35305	2.016	1.3956	3.471	135	.0006	2.852	561.7	3.77	1.43	516.3
100.00	0.00	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.4	8.22	1.55	560.7
300.00	0.00	283	34394	2.016	1.4058	3.415	85	.0003	4.499	608.7	17.15	1.63	588.0
1000.00	0.00	198	34111	2.016	1.4434	3.214	64	.0002	5.495	622.6	38.67	1.68	608.6
3000.00	0.00	140	33929	2.016	1.4888	3.007	47	.0002	6.576	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	1400	38367	2.016	1.3524	3.795	250	0.0012					
1.87	0.78	1186	37568	2.016	1.3677	3.667	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	0.49	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	0.15	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	0.05	547	35305	2.016	1.3956	3.471	135	.0006	2.852	561.7	3.77	1.43	516.3
100.00	0.01	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	0.00	283	34394	2.016	1.4058	3.415	85	.0003	4.499	608.6	17.15	1.63	588.0
1000.00	0.00	198	34111	2.016	1.4431	3.211	64	.0002	5.494	622.6	38.67	1.68	608.6
3000.00	0.00	140	33929	2.016	1.4889	3.000	47	.0002	6.575	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	1400	38367	2.016	1.3525	3.795	250	0.0012					
1.87	2.36	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	1.47	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	0.46	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	0.15	547	35304	2.016	1.3956	3.471	135	.0006	2.852	561.7	3.77	1.43	516.3
100.00	0.04	388	34755	2.016	1.3986	3.460	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	0.01	283	34394	2.016	1.4058	3.415	85	.0003	4.499	608.6	17.15	1.63	588.0
1000.00	0.00	198	34111	2.016	1.4436	3.208	64	.0002	5.493	622.5	38.67	1.68	608.6
3000.00	0.00	140	33929	2.016	1.4897	3.003	47	.0002	6.576	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	1400	38367	2.016	1.3528	3.795	250	0.0012					
1.87	7.86	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	4.90	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	1.47	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	0.49	547	35304	2.016	1.3957	3.471	135	.0006	2.852	561.6	3.77	1.43	516.3
100.00	0.15	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	0.05	283	34394	2.016	1.4059	3.415	85	.0003	4.499	608.6	17.15	1.63	588.0
1000.00	0.01	198	34111	2.016	1.4430	3.211	64	.0002	5.494	622.5	38.67	1.68	608.6
3000.00	0.00	140	33929	2.016	1.4897	3.003	47	.0002	6.577	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	1400	38367	2.016	1.3529	3.795	250	0.0012					
1.87	23.52	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	14.70	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	4.41	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	1.47	547	35304	2.016	1.3966	3.471	135	.0006	2.852	561.6	3.77	1.43	516.3
100.00	0.46	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	0.15	283	34394	2.016	1.4058	3.415	85	.0003	4.499	608.6	17.15	1.63	588.0
1000.00	0.04	198	34111	2.016	1.4429	3.211	64	.0002	5.494	622.5	38.67	1.68	608.6
3000.00	0.01	140	33929	2.016	1.4887	3.003	47	.0002	6.577	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	1400	38367	2.016	1.3530	3.795	250	0.0012					
1.87	78.45	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	48.98	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	14.70	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	4.90	547	35304	2.016	1.3966	3.471	135	.0006	2.852	561.6	3.77	1.43	516.3
100.00	1.47	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	0.49	283	34394	2.016	1.4057	3.415	85	.0003	4.499	608.6	17.15	1.63	588.0
1000.00	0.15	198	34111	2.016	1.4424	3.214	64	.0002	5.495	622.5	38.67	1.68	608.6
3000.00	0.05	140	33929	2.016	1.4887	3.007	47	.0002	6.578	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	1400	38367	2.016	1.3530	3.795	250	0.0012					
1.87	235.21	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	146.96	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	44.09	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	14.70	547	35304	2.016	1.3966	3.471	135	.0006	2.852	561.6	3.77	1.43	516.3
100.00	4.41	388	34755	2.016	1.3988	3.459	107	.0005	3.673	590.3	8.22	1.55	560.6
300.00	1.47	283	34394	2.016	1.4058	3.415	85	.0003	4.499	608.6	17.15	1.63	587.9
1000.00	0.44	198	34111	2.016	1.4429	3.211	64	.0002	5.494	622.5	38.67	1.68	608.6
3000.00	0.15	140	33929	2.016	1.4887	3.003	47	.0002	6.577	631.1	80.12	1.72	621.4
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	1400	38367	2.016	1.3530	3.795	250	0.0012					
1.87	784.05	1186	37568	2.016	1.3677	3.666	224	.0011	1.000	456.5	1.00	0.73	263.7
3.00	489.87	1043	37052	2.016	1.3772	3.599	206	.0010	1.363	470.5	1.09	0.94	338.3
10.00	146.96	746	35999	2.016	1.3922	3.499	166	.0007	2.150	524.4	1.95	1.26	453.9
30.00	48.99	547	35304	2.016	1.3966	3.471	135	.0006	2.852	561.6	3.77	1.43	516.3
100.00	14.70	388	34755	2.016	1.3986	3.459	107	.0005	3.674	590.3	8.22	1.55	560.6
300.00	4.90	283	34394	2.016	1.4058	3.414	85	.0003	4.499	608.6	17.15	1.63	587.9
1000.00	1.47	198	34111	2.016	1.4429	3.214	64	.0002	5.495	622.5	38.67	1.68	608.6
3000.00	0.49	140	33929	2.016	1.4887	3.005	47	.0002	6.578	631.0	80.12	1.72	621.4

E-692

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(d) Chamber temperature, 1600° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	1600	39147	2.016	1.3273	4.033	273	0.0014					
1.87	0.08	1365	38236	2.016	1.3537	3.775	246	.0012	1.000	489.5	1.00	0.73	281.5
3.00	0.05	1204	37638	2.016	1.3663	3.677	226	.0011	1.365	505.0	1.10	0.93	362.5
10.00	0.01	865	36418	2.016	1.3870	3.533	183	.0008	2.148	563.5	1.96	1.26	487.3
30.00	0.00	635	35612	2.016	1.3947	3.483	149	.0007	2.846	603.8	3.79	1.43	554.7
100.00	0.00	451	34973	2.016	1.3969	3.469	118	.0005	3.666	634.8	8.27	1.55	602.7
300.00	0.00	330	34553	2.016	1.4025	3.434	95	.0004	4.489	654.6	17.29	1.63	633.7
1000.00	0.00	233	34223	2.016	1.4229	3.317	73	.0003	5.495	669.8	39.25	1.69	654.6
3000.00	0.00	166	34009	2.016	1.4674	3.095	55	.0002	6.544	679.3	82.23	1.72	668.7
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	1600	39141	2.016	1.3328	3.968	273	0.0014					
1.87	0.24	1364	38231	2.016	1.3546	3.768	246	.0012	1.000	489.2	1.00	0.73	281.5
3.00	0.15	1203	37631	2.016	1.3664	3.676	226	.0011	1.365	504.7	1.10	0.93	362.4
10.00	0.04	864	36414	2.016	1.3870	3.533	183	.0008	2.148	563.2	1.96	1.26	487.1
30.00	0.01	634	35609	2.016	1.3947	3.483	149	.0007	2.846	603.5	3.79	1.43	554.1
100.00	0.00	451	34971	2.016	1.3970	3.469	118	.0005	3.666	634.4	8.27	1.55	602.4
300.00	0.00	329	34552	2.016	1.4025	3.435	95	.0004	4.489	654.2	17.29	1.63	633.4
1000.00	0.00	232	34222	2.016	1.4226	3.318	73	.0003	5.496	669.5	39.25	1.69	654.2
3000.00	0.00	166	34008	2.016	1.4689	3.088	55	.0002	6.542	678.9	82.22	1.72	668.3
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	1600	39137	2.016	1.3363	3.928	273	0.0014					
1.87	0.79	1363	38227	2.016	1.3550	3.763	246	.0012	1.000	489.1	1.00	0.73	281.4
3.00	0.49	1202	37628	2.016	1.3666	3.675	226	.0011	1.365	504.6	1.10	0.93	362.4
10.00	0.15	864	36412	2.016	1.3870	3.533	183	.0008	2.148	563.0	1.96	1.26	486.9
30.00	0.05	634	35607	2.016	1.3947	3.483	149	.0007	2.846	603.3	3.79	1.43	553.9
100.00	0.01	450	34970	2.016	1.3969	3.469	118	.0005	3.666	634.2	8.27	1.55	602.2
300.00	0.00	329	34551	2.016	1.4025	3.435	95	.0004	4.489	654.0	17.29	1.63	633.2
1000.00	0.00	232	34221	2.016	1.4221	3.321	73	.0003	5.497	669.3	39.25	1.69	654.0
3000.00	0.00	166	34008	2.016	1.4676	3.094	55	.0002	6.545	678.7	82.22	1.72	668.1
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	1600	39135	2.016	1.3381	3.908	273	0.0014					
1.87	2.36	1362	38225	2.016	1.3552	3.751	246	.0012	1.000	489.0	1.00	0.73	281.4
3.00	1.47	1201	37627	2.016	1.3666	3.675	226	.0011	1.365	504.5	1.10	0.93	362.4
10.00	0.44	863	36411	2.016	1.3870	3.532	183	.0008	2.148	562.9	1.96	1.26	486.9
30.00	0.15	634	35607	2.016	1.3947	3.483	149	.0007	2.846	603.2	3.79	1.43	553.1
100.00	0.04	450	34969	2.016	1.3969	3.469	118	.0005	3.666	634.1	8.27	1.55	602.1
300.00	0.01	329	34551	2.016	1.4025	3.435	95	.0004	4.489	653.9	17.29	1.63	631.6
1000.00	0.00	232	34221	2.016	1.4226	3.318	73	.0003	5.496	669.1	39.25	1.69	653.9
3000.00	0.00	165	34007	2.016	1.4668	3.098	55	.0002	6.547	678.6	82.21	1.72	668.0
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	1600	39134	2.016	1.3392	3.895	273	0.0014					
1.87	7.87	1362	38224	2.016	1.3554	3.760	245	.0012	1.000	489.0	1.00	0.73	281.4
3.00	4.90	1201	37626	2.016	1.3666	3.674	226	.0011	1.366	504.5	1.10	0.93	362.3
10.00	1.47	863	36410	2.016	1.3870	3.532	183	.0008	2.148	562.9	1.96	1.26	486.8
30.00	0.49	634	35606	2.016	1.3947	3.483	149	.0007	2.846	603.1	3.79	1.43	553.1
100.00	0.15	450	34969	2.016	1.3969	3.469	118	.0005	3.666	634.1	8.27	1.55	602.0
300.00	0.05	329	34551	2.016	1.4026	3.434	95	.0004	4.489	653.9	17.29	1.63	631.6
1000.00	0.01	232	34221	2.016	1.4226	3.318	73	.0003	5.496	669.1	39.25	1.69	653.9
3000.00	0.00	165	34007	2.016	1.4675	3.094	55	.0002	6.546	678.5	82.21	1.72	667.9
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	1600	39133	2.016	1.3398	3.888	273	0.0014					
1.87	23.61	1362	38224	2.016	1.3555	3.759	245	.0012	1.000	489.0	1.00	0.73	281.4
3.00	14.70	1201	37625	2.016	1.3666	3.674	226	.0011	1.366	504.4	1.10	0.93	362.3
10.00	4.41	863	36410	2.016	1.3871	3.532	183	.0008	2.148	562.8	1.96	1.26	486.8
30.00	1.47	633	35606	2.016	1.3947	3.483	149	.0007	2.846	603.1	3.79	1.43	553.0
100.00	0.44	450	34969	2.016	1.3969	3.469	118	.0005	3.666	634.0	8.27	1.55	602.0
300.00	0.15	329	34550	2.016	1.4025	3.435	95	.0004	4.489	653.8	17.29	1.63	631.5
1000.00	0.04	232	34221	2.016	1.4222	3.321	73	.0003	5.497	669.0	39.25	1.69	653.8
3000.00	0.01	165	34007	2.016	1.4677	3.093	55	.0002	6.545	678.5	82.21	1.72	667.8
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	1600	39133	2.016	1.3402	3.885	273	0.0014					
1.87	78.71	1362	38224	2.016	1.3555	3.759	245	.0012	1.000	488.9	1.00	0.73	281.4
3.00	48.99	1201	37625	2.016	1.3667	3.674	226	.0011	1.366	504.4	1.10	0.93	362.3
10.00	14.70	863	36410	2.016	1.3871	3.532	183	.0008	2.148	562.8	1.96	1.26	486.8
30.00	4.90	633	35606	2.016	1.3947	3.483	149	.0007	2.846	603.1	3.79	1.43	553.0
100.00	1.47	450	34969	2.016	1.3969	3.469	118	.0005	3.666	634.0	8.27	1.55	602.0
300.00	0.49	329	34550	2.016	1.4025	3.435	95	.0004	4.489	653.8	17.29	1.63	631.5
1000.00	0.15	232	34221	2.016	1.4222	3.321	73	.0003	5.497	669.0	39.25	1.69	653.8
3000.00	0.05	165	34007	2.016	1.4677	3.093	55	.0002	6.546	678.5	82.21	1.72	667.8
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	1600	39133	2.016	1.3404	3.882	273	0.0014					
1.87	236.14	1361	38223	2.016	1.3555	3.758	245	.0012	1.000	488.9	1.00	0.73	281.4
3.00	146.96	1201	37625	2.016	1.3667	3.674	226	.0011	1.366	504.4	1.10	0.93	362.3
10.00	44.09	863	36410	2.016	1.3871	3.532	183	.0008	2.148	562.8	1.96	1.26	486.8
30.00	14.70	633	35606	2.016	1.3947	3.483	149	.0007	2.846	603.0	3.79	1.43	553.0
100.00	4.41	450	34969	2.016	1.3968	3.470	118	.0005	3.666	634.0	8.27	1.55	601.9
300.00	1.47	329	34550	2.016	1.4026	3.434	95	.0004	4.489	653.8	17.29	1.63	631.5
1000.00	0.44	232	34221	2.016	1.4229	3.317	73	.0003	5.496	669.0	39.25	1.69	653.8
3000.00	0.15	165	34007	2.016	1.4677	3.093	55	.0002	6.546	678.5	82.21	1.72	667.8
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	1600	39133	2.016	1.3405	3.881	273	0.0013					
1.87	787.14	1362	38223	2.016	1.3555	3.758	245	.0012	1.000	488.9	1.00	0.73	281.4
3.00	489.87	1201	37625	2.016	1.3667	3.674	226	.0011	1.366	504.4	1.10	0.93	362.3
10.00	146.96	863	36410	2.016	1.3871	3.532	183	.0008	2.148	562.8	1.96	1.26	486.8
30.00	48.99	633	35606	2.016	1.3948	3.483	149	.0007	2.846	603.0	3.79	1.43	552.9
100.00	14.70	450	34969	2.016	1.3969	3.469	118	.0005	3.666	634.0	8.27	1.55	601.9
300.00	4.90	329	34550	2.016	1.4025	3.435	95	.0004	4.489	653.8	17.29	1.63	631.5
1000.00	1.47	232	34221	2.016	1.4221	3.321	73	.0003	5.497	669.0	39.25	1.69	653.8
3000.00	0.49	165	34007	2.016	1.4677	3.093	55	.0002	6.546	678.5	82.21	1.72	667.8

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(e) Chamber temperature, 1800° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, $\bar{F}$	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	1800	40014	2.012	1.2771	4.779	294	0.0017					
1.85	0.08	1560	38991	2.016	1.3304	4.007	268	.0014	1.000	522.6	1.00	0.72	298.6
3.00	0.05	1380	38294	2.016	1.3519	3.791	248	.0012	1.368	539.9	1.10	0.93	386.9
10.00	0.01	999	36892	2.016	1.3801	3.579	201	.0009	2.144	603.4	1.97	1.25	521.2
30.00	0.00	735	35960	2.016	1.3927	3.496	165	.0007	2.835	647.0	3.83	1.43	593.0
100.00	0.00	523	35221	2.016	1.3973	3.467	131	.0006	3.649	680.5	8.34	1.55	645.8
300.00	0.00	382	34735	2.016	1.3989	3.457	105	.0004	4.475	702.0	17.46	1.63	677.8
1000.00	0.00	271	34351	2.016	1.4081	3.401	82	.0003	5.491	718.5	39.76	1.69	702.0
3000.00	0.00	195	34100	2.016	1.4460	3.196	63	.0002	6.522	729.0	84.14	1.73	719.5
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	1800	39973	2.016	1.2965	4.419	294	0.0016					
1.86	0.24	1551	38951	2.016	1.3366	3.931	267	.0013	1.000	521.3	1.00	0.72	298.2
3.00	0.15	1372	38261	2.016	1.3536	3.775	247	.0012	1.368	538.4	1.10	0.93	386.0
10.00	0.04	992	36868	2.016	1.3804	3.577	200	.0009	2.145	601.6	1.97	1.25	519.8
30.00	0.01	735	35942	2.016	1.3929	3.495	164	.0007	2.835	645.1	3.82	1.43	591.5
100.00	0.00	519	35208	2.016	1.3974	3.466	130	.0006	3.651	678.6	8.34	1.55	643.9
300.00	0.00	380	34725	2.016	1.3990	3.456	105	.0004	4.477	699.9	17.45	1.63	675.8
1000.00	0.00	269	34344	2.016	1.4084	3.398	81	.0003	5.493	716.3	39.74	1.69	699.9
3000.00	0.00	194	34096	2.016	1.4466	3.198	63	.0002	6.528	726.8	84.07	1.73	715.1
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	1800	39948	2.015	1.3104	4.330	294	0.0016					
1.86	0.79	1546	38927	2.016	1.3402	3.892	267	.0013	1.000	520.5	1.00	0.72	298.1
3.00	0.49	1366	38240	2.016	1.3546	3.767	246	.0012	1.368	537.5	1.10	0.93	385.8
10.00	0.15	988	36854	2.016	1.3807	3.575	199	.0009	2.146	600.6	1.97	1.26	518.9
30.00	0.05	727	35932	2.016	1.3930	3.494	163	.0007	2.837	643.9	3.82	1.43	591.0
100.00	0.01	517	35201	2.016	1.3975	3.465	130	.0006	3.652	677.2	8.34	1.55	642.7
300.00	0.00	378	34720	2.016	1.3991	3.456	105	.0004	4.478	698.5	17.45	1.63	674.2
1000.00	0.00	268	34340	2.016	1.4088	3.397	81	.0003	5.495	715.0	39.73	1.69	698.5
3000.00	0.00	193	34093	2.016	1.4462	3.195	63	.0002	6.529	725.2	84.02	1.73	713.9
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	1800	39936	2.015	1.3182	4.122	294	0.0015					
1.86	2.37	1543	38915	2.016	1.3419	3.873	266	.0013	1.000	520.1	1.00	0.72	298.0
3.00	1.47	1364	38230	2.016	1.3551	3.762	246	.0012	1.368	537.0	1.10	0.93	385.5
10.00	0.44	986	36846	2.016	1.3808	3.574	199	.0009	2.146	600.0	1.97	1.26	518.5
30.00	0.15	725	35926	2.016	1.3931	3.493	163	.0007	2.837	643.3	3.82	1.43	590.7
100.00	0.04	516	35197	2.016	1.3976	3.465	130	.0006	3.652	676.6	8.34	1.56	642.1
300.00	0.01	377	34717	2.016	1.3992	3.455	104	.0004	4.478	697.9	17.44	1.63	673.7
1000.00	0.00	267	34338	2.016	1.4092	3.395	81	.0003	5.495	714.3	39.73	1.69	697.9
3000.00	0.00	192	34091	2.016	1.4466	3.193	62	.0002	6.530	724.7	84.00	1.73	713.3
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	1800	39928	2.016	1.3233	4.056	295	0.0015					
1.86	7.90	1541	38907	2.016	1.3430	3.862	266	.0013	1.000	519.8	1.00	0.72	298.0
3.00	4.90	1362	38224	2.016	1.3553	3.760	245	.0012	1.369	536.7	1.10	0.93	385.1
10.00	1.47	985	36842	2.016	1.3808	3.574	199	.0009	2.146	599.7	1.97	1.26	518.2
30.00	0.49	724	35923	2.016	1.3931	3.493	163	.0007	2.838	642.9	3.82	1.43	590.3
100.00	0.15	515	35194	2.016	1.3975	3.465	130	.0006	3.653	676.2	8.34	1.56	641.8
300.00	0.05	377	34715	2.016	1.3991	3.455	104	.0004	4.479	697.5	17.44	1.63	673.4
1000.00	0.01	267	34337	2.016	1.4090	3.396	81	.0003	5.496	713.9	39.73	1.69	697.5
3000.00	0.00	192	34091	2.016	1.4475	3.189	62	.0002	6.529	724.2	84.99	1.73	712.7
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	1800	39924	2.016	1.3260	4.022	295	0.0015					
1.86	23.71	1541	38904	2.016	1.3435	3.857	266	.0013	1.000	519.7	1.00	0.72	297.9
3.00	14.70	1361	38221	2.016	1.3555	3.759	245	.0012	1.369	536.5	1.10	0.93	385.0
10.00	4.41	984	36839	2.016	1.3809	3.574	199	.0009	2.146	599.5	1.97	1.26	518.1
30.00	1.47	724	35921	2.016	1.3931	3.493	163	.0007	2.838	642.8	3.82	1.43	590.1
100.00	0.44	515	35193	2.016	1.3976	3.465	130	.0006	3.653	676.0	8.34	1.56	641.6
300.00	0.15	377	34714	2.016	1.3992	3.455	104	.0004	4.479	697.3	17.44	1.63	673.1
1000.00	0.04	266	34336	2.016	1.4090	3.396	81	.0003	5.496	713.6	39.73	1.69	697.3
3000.00	0.01	192	34090	2.016	1.4469	3.192	62	.0002	6.530	724.0	84.98	1.73	712.6
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	1800	39921	2.016	1.3276	4.001	295	0.0015					
1.86	79.01	1540	38901	2.016	1.3438	3.853	266	.0013	1.000	519.6	1.00	0.72	297.9
3.00	48.99	1361	38219	2.016	1.3556	3.758	245	.0012	1.369	536.5	1.10	0.93	384.9
10.00	14.70	984	36838	2.016	1.3809	3.574	199	.0009	2.146	599.4	1.97	1.26	518.0
30.00	4.90	724	35920	2.016	1.3931	3.493	163	.0007	2.838	642.6	3.82	1.43	590.0
100.00	1.47	514	35192	2.016	1.3976	3.465	129	.0006	3.653	675.9	8.34	1.56	641.4
300.00	0.49	376	34714	2.016	1.3993	3.454	104	.0004	4.479	697.1	17.44	1.63	673.1
1000.00	0.15	266	34336	2.016	1.4091	3.395	81	.0003	5.496	713.5	39.73	1.69	697.1
3000.00	0.05	192	34090	2.016	1.4476	3.188	62	.0002	6.529	723.9	83.98	1.73	712.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	1800	39920	2.016	1.3285	3.990	295	0.0015					
1.86	237.02	1540	38900	2.016	1.3440	3.852	266	.0013	1.000	519.6	1.00	0.72	297.9
3.00	146.96	1360	38218	2.016	1.3556	3.758	245	.0012	1.369	536.5	1.10	0.93	384.9
10.00	44.09	983	36837	2.016	1.3809	3.573	199	.0009	2.146	599.4	1.97	1.26	517.9
30.00	14.70	723	35920	2.016	1.3931	3.493	163	.0007	2.838	642.6	3.82	1.43	590.0
100.00	4.41	514	35192	2.016	1.3975	3.465	129	.0006	3.653	675.8	8.34	1.56	641.4
300.00	1.47	376	34713	2.016	1.3992	3.455	104	.0004	4.479	697.1	17.44	1.63	673.1
1000.00	0.44	266	34336	2.016	1.4089	3.397	81	.0003	5.496	713.4	39.73	1.69	697.1
3000.00	0.15	192	34090	2.016	1.4471	3.191	62	.0002	6.530	723.8	83.98	1.73	712.5
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	1800	39919	2.016	1.3290	3.983	295	0.0015					
1.86	790.06	1540	38899	2.016	1.3441	3.851	266	.0013	1.000	519.5	1.00	0.72	297.9
3.00	489.87	1360	38217	2.016	1.3557	3.757	245	.0012	1.369	536.4	1.10	0.93	384.9
10.00	146.96	983	36837	2.016	1.3809	3.573	199	.0009	2.146	599.3	1.97	1.26	517.9
30.00	49.99	723	35919	2.016	1.3931	3.493	163	.0007	2.838	642.5	3.82	1.43	590.0
100.00	14.70	514	35192	2.016	1.3976	3.465	129	.0006	3.653	675.8	8.34	1.56	641.4
300.00	4.90	376	34713	2.016	1.3992	3.455	104	.0004	4.479	697.0	17.44	1.63	673.1
1000.00	1.47	266	34336	2.016	1.4092	3.395	81	.0003	5.496	713.4	39.73	1.69	697.0
3000.00	0.49	192	34090	2.016	1.4479	3.188	62	.0002	6.529	723.8	83.98	1.73	712.5

E-692

E-692

CT-3 back

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(f) Chamber temperature, 2000° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	2000	41158	2.000	1.2044	7.043	315	0.0026					
1.81	0.08	1798	40035	2.011	1.2644	5.039	294	.0018	1.000	559.8	1.00	0.70	312.6
3.00	0.05	1608	39190	2.015	1.3164	4.169	274	.0014	1.373	580.5	1.11	0.92	413.8
10.00	0.01	1179	37545	2.016	1.3679	3.665	223	.0010	2.132	650.9	2.01	1.25	560.7
30.00	0.00	872	36442	2.016	1.3866	3.535	184	.0008	2.813	699.0	3.90	1.42	640.6
100.00	0.00	621	35563	2.016	1.3949	3.482	147	.0006	3.619	735.9	8.51	1.55	697.7
300.00	0.00	455	34985	2.016	1.3969	3.469	119	.0005	4.440	759.5	17.79	1.63	732.0
1000.00	0.00	323	34528	2.016	1.4031	3.431	93	.0004	5.452	777.7	40.59	1.69	759.5
3000.00	0.00	234	34229	2.016	1.4213	3.325	73	.0003	6.495	789.4	86.58	1.73	775.5
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	2000	40974	2.007	1.2366	5.784	315	0.0022					
1.83	0.24	1767	39844	2.014	1.2959	4.452	291	.0016	1.000	555.5	1.00	0.71	313.5
3.00	0.15	1572	39034	2.016	1.3318	3.983	270	.0014	1.371	574.0	1.10	0.93	410.9
10.00	0.04	1148	37426	2.016	1.3792	3.648	219	.0010	2.138	643.9	1.99	1.25	555.3
30.00	0.01	848	36359	2.016	1.3878	3.528	181	.0008	2.821	691.2	3.97	1.43	633.8
100.00	0.00	604	35503	2.016	1.3953	3.479	144	.0006	3.629	727.5	8.46	1.56	690.0
300.00	0.00	442	34941	2.016	1.3969	3.469	117	.0005	4.449	750.7	17.69	1.63	724.5
1000.00	0.00	313	34497	2.016	1.4036	3.428	91	.0004	5.466	768.6	40.35	1.69	750.7
3000.00	0.00	228	34206	2.016	1.4253	3.303	72	.0003	6.506	780.1	86.00	1.73	767.4
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	2000	40860	2.011	1.2660	5.007	315	0.0019					
1.84	0.80	1746	39729	2.015	1.3146	4.179	289	.0015	1.000	552.5	1.00	0.71	313.8
3.00	0.49	1549	38939	2.016	1.3389	3.905	267	.0013	1.371	571.3	1.10	0.93	408.9
10.00	0.15	1129	37360	2.016	1.3716	3.639	217	.0010	2.142	639.5	1.99	1.25	551.8
30.00	0.05	833	36305	2.016	1.3884	3.523	179	.0008	2.826	686.3	3.96	1.43	629.5
100.00	0.01	593	35466	2.016	1.3955	3.478	143	.0006	3.635	722.2	8.43	1.56	685.1
300.00	0.00	434	34914	2.016	1.3971	3.468	115	.0005	4.459	745.2	17.64	1.63	719.3
1000.00	0.00	308	34478	2.016	1.4043	3.424	90	.0004	5.473	762.9	40.25	1.69	745.2
3000.00	0.00	223	34193	2.016	1.4272	3.293	71	.0003	6.513	774.3	85.73	1.73	761.7
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	2000	40802	2.013	1.2856	4.609	315	0.0018					
1.85	2.38	1734	39671	2.015	1.3233	4.065	287	.0015	1.000	550.8	1.00	0.70	313.7
3.00	1.47	1537	38891	2.016	1.3419	3.874	266	.0013	1.371	569.4	1.10	0.93	407.8
10.00	0.44	1119	37325	2.016	1.3722	3.634	216	.0010	2.143	637.2	1.99	1.25	550.0
30.00	0.15	826	36279	2.016	1.3888	3.521	178	.0008	2.828	683.8	3.86	1.43	627.3
100.00	0.04	588	35448	2.016	1.3956	3.477	142	.0006	3.638	719.5	8.43	1.56	682.6
300.00	0.01	430	34901	2.016	1.3971	3.468	115	.0005	4.462	742.3	17.63	1.63	716.4
1000.00	0.00	305	34469	2.016	1.4045	3.423	90	.0004	5.476	760.0	40.21	1.69	742.4
3000.00	0.00	221	34186	2.016	1.4280	3.289	70	.0003	6.518	771.3	85.61	1.73	758.8
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	2000	40766	2.014	1.2999	4.353	315	0.0017					
1.85	7.94	1727	39635	2.016	1.3283	4.003	287	.0015	1.000	549.8	1.00	0.72	313.7
3.00	4.90	1529	38861	2.016	1.3436	3.858	265	.0013	1.371	568.2	1.10	0.93	407.1
10.00	1.47	1113	37304	2.016	1.3726	3.631	215	.0010	2.144	635.8	1.98	1.26	548.9
30.00	0.49	822	36264	2.016	1.3890	3.520	177	.0008	2.829	682.2	3.86	1.43	625.9
100.00	0.15	585	35437	2.016	1.3957	3.477	141	.0006	3.640	717.8	8.43	1.56	681.0
300.00	0.05	428	34893	2.016	1.3971	3.468	114	.0005	4.464	740.6	17.62	1.64	714.9
1000.00	0.01	303	34463	2.016	1.4047	3.421	89	.0004	5.478	758.2	40.18	1.69	740.6
3000.00	0.00	220	34181	2.016	1.4293	3.282	70	.0003	6.518	769.4	85.55	1.73	756.3
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	2000	40748	2.015	1.3080	4.237	315	0.0017					
1.85	23.80	1723	39617	2.016	1.3308	3.974	286	.0014	1.000	549.2	1.00	0.72	313.6
3.00	14.70	1526	38846	2.016	1.3444	3.850	264	.0013	1.371	567.6	1.10	0.93	406.8
10.00	4.41	1110	37293	2.016	1.3728	3.629	215	.0010	2.145	635.1	1.98	1.26	548.3
30.00	1.47	819	36255	2.016	1.3891	3.519	177	.0008	2.830	681.4	3.86	1.43	625.3
100.00	0.44	583	35431	2.016	1.3957	3.477	141	.0006	3.640	716.9	8.43	1.56	680.2
300.00	0.15	427	34888	2.016	1.3972	3.468	114	.0005	4.465	739.7	17.61	1.64	713.5
1000.00	0.04	302	34460	2.016	1.4049	3.420	89	.0004	5.479	757.2	40.17	1.69	739.7
3000.00	0.01	219	34179	2.016	1.4289	3.284	69	.0003	6.521	768.4	85.52	1.73	756.0
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	2000	40735	2.015	1.3134	4.159	315	0.0017					
1.85	79.30	1721	39606	2.016	1.3323	3.957	286	.0014	1.000	548.9	1.00	0.72	313.6
3.00	48.99	1523	38837	2.016	1.3448	3.845	264	.0013	1.372	567.2	1.10	0.93	406.8
10.00	14.70	1108	37286	2.016	1.3730	3.629	214	.0010	2.145	634.6	1.98	1.26	547.9
30.00	4.90	818	36250	2.016	1.3891	3.519	176	.0008	2.830	680.9	3.86	1.43	624.8
100.00	1.47	582	35427	2.016	1.3958	3.476	141	.0006	3.641	715.4	8.42	1.56	679.7
300.00	0.49	426	34886	2.016	1.3972	3.467	114	.0005	4.465	739.1	17.61	1.64	713.5
1000.00	0.15	302	34458	2.016	1.4049	3.420	89	.0004	5.480	756.6	40.17	1.69	739.1
3000.00	0.05	219	34178	2.016	1.4298	3.279	69	.0003	6.520	767.9	85.50	1.73	755.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	2000	40730	2.016	1.3162	4.119	315	0.0016					
1.85	237.86	1719	39601	2.016	1.3330	3.948	286	.0014	1.000	548.7	1.00	0.72	313.5
3.00	146.96	1522	38832	2.016	1.3451	3.843	264	.0013	1.372	567.0	1.10	0.93	406.4
10.00	44.09	1107	37283	2.016	1.3730	3.628	214	.0010	2.145	634.4	1.98	1.26	547.7
30.00	14.70	817	36248	2.016	1.3892	3.518	176	.0008	2.831	680.6	3.86	1.43	624.5
100.00	4.41	582	35425	2.016	1.3958	3.476	141	.0006	3.641	716.1	8.42	1.56	679.4
300.00	1.47	426	34884	2.016	1.3972	3.468	114	.0005	4.466	738.8	17.61	1.64	713.2
1000.00	0.44	302	34457	2.016	1.4051	3.419	89	.0004	5.480	756.3	40.16	1.69	739.4
3000.00	0.15	219	34177	2.016	1.4299	3.279	69	.0003	6.520	767.5	85.49	1.73	755.1
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	2000	40727	2.016	1.3179	4.095	315	0.0016					
1.85	793.78	1719	39597	2.016	1.3335	3.943	285	.0014	1.000	548.6	1.00	0.72	313.5
3.00	489.87	1521	38829	2.016	1.3452	3.841	264	.0013	1.372	566.9	1.10	0.93	406.3
10.00	146.96	1107	37281	2.016	1.3731	3.628	214	.0010	2.145	634.3	1.98	1.26	547.6
30.00	48.99	817	36246	2.016	1.3892	3.518	176	.0008	2.831	680.5	3.86	1.43	624.4
100.00	14.70	581	35424	2.016	1.3958	3.476	141	.0006	3.641	716.0	8.42	1.56	679.2
300.00	4.90	425	34884	2.016	1.3972	3.468	114	.0005	4.466	738.6	17.61	1.64	713.0
1000.00	1.47	302	34456	2.016	1.4049	3.420	89	.0004	5.480	756.2	40.16	1.69	738.7
3000.00	0.49	219	34177	2.016	1.4299	3.279	69	.0003	6.520	767.4	85.48	1.73	754.9

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(g) Chamber temperature, 2200° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	2200	43056	1.961	1.1485	12.713	333	0.0046					
1.75	0.08	2062	41850	1.984	1.1434	9.708	321	.0035	1.000	601.4	1.00	0.67	323.9
3.00	0.05	1914	40784	2.001	1.2025	7.074	305	.0025	1.410	630.7	1.14	0.91	444.6
10.00	0.01	1496	38746	2.015	1.3314	3.997	261	.0013	2.095	717.2	2.15	1.26	612.5
30.00	0.00	1121	37335	2.016	1.3719	3.436	215	.0010	2.747	773.7	4.20	1.45	705.6
100.00	0.00	806	36202	2.016	1.3898	3.515	174	.0008	3.528	816.9	9.17	1.59	772.3
300.00	0.00	590	35453	2.016	1.3956	3.477	142	.0006	4.330	844.5	19.17	1.67	813.4
1000.00	0.00	419	34860	2.016	1.3974	3.466	112	.0005	5.331	865.7	43.71	1.74	844.6
3000.00	0.00	306	34471	2.016	1.4044	3.473	90	.0004	6.368	879.5	93.58	1.78	864.3
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	2200	42417	1.984	1.1767	9.095	334	0.0034					
1.78	0.25	2032	41200	2.007	1.2126	5.678	317	.0025	1.000	593.8	1.00	0.68	325.4
3.00	0.15	1839	40203	2.011	1.2638	5.053	298	.0018	1.389	619.0	1.19	0.92	438.9
10.00	0.04	1380	38294	2.016	1.3517	3.793	248	.0012	2.117	697.8	2.06	1.25	599.0
30.00	0.01	1028	36998	2.015	1.3787	3.592	204	.0009	2.746	750.9	4.02	1.44	694.2
100.00	0.00	735	35960	2.016	1.3927	3.496	165	.0007	3.577	791.6	8.73	1.57	749.5
300.00	0.00	539	35276	2.016	1.3969	3.469	134	.0006	4.388	817.6	18.39	1.65	788.3
1000.00	0.00	382	34736	2.016	1.3990	3.456	105	.0004	5.397	837.7	41.04	1.71	817.6
3000.00	0.00	279	34379	2.015	1.4064	3.411	84	.0003	6.447	850.6	89.75	1.76	836.3
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	2200	42022	1.998	1.2168	6.856	335	0.0027					
1.81	0.81	1978	40391	2.010	1.2560	4.167	313	.0020	1.000	587.2	1.00	0.70	327.3
3.00	0.49	1774	39856	2.014	1.3041	4.325	292	.0016	1.378	609.5	1.11	0.92	434.1
10.00	0.15	1311	38033	2.016	1.3564	3.737	239	.0011	2.132	684.6	2.02	1.25	589.1
30.00	0.05	974	36804	2.016	1.3814	3.570	197	.0009	2.805	735.8	3.95	1.43	673.8
100.00	0.01	695	35822	2.016	1.3941	3.487	159	.0007	3.602	775.1	8.62	1.56	734.5
300.00	0.00	509	35174	2.016	1.3978	3.464	129	.0006	4.418	800.2	18.09	1.64	771.0
1000.00	0.00	362	34663	2.016	1.4001	3.449	101	.0004	5.431	819.6	41.16	1.70	800.2
3000.00	0.00	264	34327	2.016	1.4100	3.390	80	.0003	6.482	832.1	88.02	1.74	818.3
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	2200	41820	2.006	1.2402	5.710	335	0.0023					
1.83	2.41	1947	40583	2.013	1.2876	4.537	310	.0018	1.000	583.0	1.00	0.70	328.1
3.00	1.47	1736	39683	2.015	1.3204	4.107	288	.0015	1.395	603.9	1.11	0.93	431.3
10.00	0.44	1277	37905	2.016	1.3612	3.715	235	.0011	2.138	677.5	2.01	1.25	583.7
30.00	0.15	947	36708	2.016	1.3828	3.560	194	.0009	2.814	727.8	3.92	1.43	666.0
100.00	0.04	676	35753	2.016	1.3942	3.486	156	.0007	3.614	766.4	8.56	1.56	726.5
300.00	0.01	495	35125	2.016	1.3978	3.464	126	.0005	4.431	791.1	17.90	1.64	763.3
1000.00	0.00	351	34627	2.016	1.4008	3.445	99	.0004	5.446	810.1	40.87	1.70	791.1
3000.00	0.00	256	34301	2.016	1.4119	3.379	78	.0003	6.498	822.4	87.38	1.74	808.8
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	2200	41695	2.010	1.2662	5.003	335	0.0020					
1.84	8.00	1975	40455	2.015	1.3054	4.239	308	.0017	1.000	580.0	1.00	0.71	328.4
3.00	4.90	1712	39577	2.016	1.3285	4.004	285	.0014	1.374	600.3	1.11	0.93	429.9
10.00	1.47	1255	37827	2.016	1.3628	3.703	233	.0011	2.143	672.5	2.00	1.25	580.1
30.00	0.49	931	36651	2.016	1.3837	3.556	192	.0009	2.819	722.8	3.91	1.43	662.4
100.00	0.15	664	35712	2.016	1.3944	3.485	154	.0007	3.621	761.0	8.53	1.56	721.5
300.00	0.05	486	35094	2.016	1.3974	3.466	125	.0005	4.440	785.6	17.85	1.64	757.4
1000.00	0.01	345	34606	2.016	1.4014	3.442	98	.0004	5.454	804.2	40.74	1.70	785.4
3000.00	0.00	251	34285	2.016	1.4140	3.367	77	.0003	6.504	816.4	87.07	1.74	802.9
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	2200	41631	2.013	1.2831	4.639	335	0.0019					
1.84	23.93	1914	40391	2.015	1.3139	4.165	306	.0016	1.000	578.4	1.00	0.71	328.6
3.00	14.70	1659	39524	2.016	1.3319	3.964	284	.0014	1.374	598.4	1.10	0.93	429.5
10.00	4.41	1245	37788	2.016	1.3635	3.697	231	.0011	2.143	670.6	2.00	1.25	578.3
30.00	1.47	923	36621	2.016	1.3841	3.552	191	.0009	2.821	720.2	3.90	1.43	660.3
100.00	0.46	658	35692	2.016	1.3944	3.485	153	.0007	3.624	758.1	8.52	1.56	718.3
300.00	0.15	482	35079	2.016	1.3973	3.467	124	.0005	4.444	782.4	17.83	1.64	754.3
1000.00	0.04	342	34595	2.016	1.4013	3.442	97	.0004	5.458	801.2	40.69	1.70	782.4
3000.00	0.01	249	34278	2.016	1.4145	3.364	77	.0003	6.509	813.2	86.93	1.74	798.5
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	2200	41591	2.014	1.2953	4.415	335	0.0018					
1.85	79.64	1906	40352	2.016	1.3199	4.096	306	.0016	1.000	577.3	1.00	0.71	328.6
3.00	48.99	1691	39491	2.016	1.3339	3.943	283	.0014	1.374	597.2	1.10	0.93	427.5
10.00	14.70	1239	37764	2.016	1.3640	3.694	231	.0011	2.144	669.1	2.00	1.26	577.1
30.00	4.90	918	36604	2.016	1.3844	3.550	190	.0009	2.822	718.5	3.90	1.43	658.8
100.00	1.47	654	35679	2.016	1.3944	3.485	152	.0007	3.626	756.4	8.51	1.56	717.3
300.00	0.49	479	35070	2.016	1.3972	3.467	123	.0005	4.446	780.6	17.81	1.64	753.3
1000.00	0.15	340	34588	2.016	1.4017	3.440	97	.0004	5.460	799.3	40.66	1.70	780.5
3000.00	0.05	248	34273	2.016	1.4155	3.358	76	.0003	6.510	811.3	86.86	1.74	796.2
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	2200	41571	2.015	1.3021	4.300	335	0.0018					
1.86	238.74	1907	40332	2.016	1.3216	4.093	305	.0016	1.000	576.8	1.00	0.72	328.3
3.00	146.96	1687	39474	2.016	1.3348	3.932	282	.0014	1.374	596.5	1.10	0.93	427.1
10.00	44.09	1235	37751	2.016	1.3644	3.692	230	.0011	2.145	668.4	2.00	1.26	576.5
30.00	14.70	915	36594	2.016	1.3845	3.549	190	.0009	2.823	717.7	3.90	1.43	658.1
100.00	4.41	653	35672	2.016	1.3945	3.484	152	.0007	3.626	755.5	8.51	1.56	716.4
300.00	1.47	478	35065	2.016	1.3972	3.468	123	.0005	4.447	779.6	17.80	1.64	752.4
1000.00	0.44	339	34585	2.016	1.4017	3.439	97	.0004	5.461	798.3	40.64	1.70	779.7
3000.00	0.15	247	34270	2.016	1.4158	3.356	76	.0003	6.511	810.3	86.82	1.74	797.0
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	2200	41559	2.015	1.3065	4.229	335	0.0018					
1.85	795.48	1909	40320	2.016	1.3231	4.043	305	.0016	1.000	576.5	1.00	0.72	328.3
3.00	489.87	1685	39464	2.016	1.3353	3.926	282	.0014	1.374	596.3	1.10	0.93	426.9
10.00	146.96	1233	37744	2.016	1.3644	3.691	230	.0011	2.145	667.9	2.00	1.26	576.1
30.00	48.99	914	36589	2.016	1.3846	3.549	190	.0009	2.823	717.2	3.89	1.43	657.6
100.00	14.70	651	35668	2.016	1.3945	3.484	152	.0007	3.627	754.9	8.51	1.56	715.9
300.00	4.90	477	35062	2.016	1.3971	3.468	123	.0005	4.448	779.0	17.80	1.64	751.8
1000.00	1.47	338	34583	2.016	1.4018	3.439	97	.0004	5.462	797.7	40.63	1.70	779.1
3000.00	0.49	246	34269	2.016	1.4161	3.355	76	.0003	6.511	809.7	86.80	1.74	796.4

E-692

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(h) Chamber temperature, 2400° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	2400	46651	1.868	1.1227	24.502	349	0.0090					
1.73	0.09	2297	45300	1.898	1.1238	21.591	340	.0078	1.000	648.0	1.00	0.65	342.9
3.00	0.05	2192	44010	1.927	1.1273	18.389	331	.0065	1.440	684.6	1.16	0.91	479.4
10.00	0.01	1948	41472	1.981	1.1539	10.942	309	.0037	2.143	798.0	2.40	1.28	671.3
30.00	0.00	1656	39492	2.011	1.2523	5.301	279	.0018	2.643	879.5	5.14	1.50	789.3
100.00	0.00	1240	37772	2.016	1.3618	3.713	231	.0011	3.266	939.5	11.49	1.67	879.0
300.00	0.00	919	36609	2.016	1.3843	3.551	190	.0009	4.001	976.9	24.04	1.78	944.8
1000.00	0.00	656	35683	2.016	1.3944	3.485	153	.0007	4.934	1005.7	54.68	1.86	976.9
3000.00	0.00	480	35073	2.016	1.3973	3.467	124	.0005	5.918	1024.2	116.91	1.91	1003.7
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	2400	44851	1.928	1.1401	16.001	352	0.0060					
1.74	0.25	2270	43527	1.955	1.1478	13.184	340	.0049	1.000	635.2	1.00	0.66	339.5
3.00	0.15	2135	42314	1.978	1.1630	10.355	328	.0038	1.426	668.5	1.15	0.91	469.8
10.00	0.04	1775	39959	2.011	1.2579	5.181	292	.0018	2.106	769.4	2.27	1.27	653.4
30.00	0.01	1370	38255	2.016	1.3511	3.800	246	.0012	2.689	835.1	4.59	1.47	753.6
100.00	0.00	991	36864	2.016	1.3805	3.576	200	.0009	3.442	884.6	9.93	1.62	833.6
300.00	0.00	729	35940	2.016	1.3929	3.494	164	.0007	4.319	916.1	20.70	1.71	882.6
1000.00	0.00	518	35206	2.016	1.3975	3.466	130	.0006	5.197	940.4	47.15	1.78	916.1
3000.00	0.00	370	34724	2.016	1.3991	3.456	105	.0004	6.222	956.0	101.01	1.82	938.4
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	2400	43734	1.967	1.1657	10.655	357	0.0042					
1.77	0.83	2229	42412	1.988	1.1872	9.286	337	.0032	1.000	624.9	1.00	0.67	339.2
3.00	0.49	2053	41281	2.003	1.2222	6.298	320	.0024	1.404	653.8	1.14	0.92	462.0
10.00	0.15	1590	39108	2.016	1.3289	4.015	272	.0014	2.107	742.0	2.13	1.26	634.5
30.00	0.05	1196	37607	2.016	1.3668	3.673	225	.0011	2.758	800.4	4.17	1.45	730.3
100.00	0.01	859	36397	2.016	1.3872	3.531	182	.0008	3.534	845.2	9.14	1.58	799.0
300.00	0.00	631	35596	2.016	1.3947	3.483	149	.0007	4.333	873.6	19.11	1.67	841.8
1000.00	0.00	448	34962	2.016	1.3969	3.470	118	.0005	5.333	895.7	43.60	1.73	873.7
3000.00	0.00	328	34545	2.016	1.4027	3.434	94	.0004	6.371	909.9	93.42	1.77	894.2
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	2400	43162	1.987	1.1946	7.953	354	0.0032					
1.79	2.46	2186	41829	2.003	1.2286	6.103	334	.0024	1.000	617.6	1.00	0.69	340.5
3.00	1.47	1981	40766	2.011	1.2710	4.898	313	.0019	1.388	643.1	1.12	0.92	456.6
10.00	0.44	1489	38709	2.014	1.3445	3.853	260	.0013	2.124	725.1	2.06	1.25	622.5
30.00	0.15	1114	37307	2.016	1.3724	3.691	215	.0010	2.787	780.7	4.04	1.44	713.7
100.00	0.04	798	36182	2.016	1.3900	3.513	174	.0008	3.572	823.3	8.94	1.57	779.3
300.00	0.01	585	35438	2.016	1.3957	3.477	141	.0006	4.380	850.4	18.50	1.65	819.8
1000.00	0.00	416	34850	2.016	1.3974	3.466	112	.0005	5.388	871.4	42.27	1.71	850.4
3000.00	0.00	304	34464	2.016	1.4047	3.421	89	.0004	6.432	884.9	90.44	1.75	870.0
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	2400	42808	2.000	1.2262	6.263	354	0.0026					
1.81	8.10	2145	41466	2.010	1.2560	5.007	330	.0020	1.000	611.7	1.00	0.70	341.7
3.00	4.90	1923	40456	2.014	1.3010	4.355	307	.0017	1.380	634.9	1.11	0.92	452.4
10.00	1.47	1428	38475	2.016	1.3504	3.800	253	.0012	2.135	713.8	2.03	1.25	614.0
30.00	0.49	1066	37133	2.016	1.3758	3.609	209	.0010	2.803	767.8	3.98	1.43	707.7
100.00	0.15	763	36057	2.016	1.3916	3.503	169	.0008	3.593	809.1	8.71	1.56	766.4
300.00	0.05	559	35347	2.016	1.3969	3.473	137	.0006	4.404	835.5	18.27	1.64	805.7
1000.00	0.01	397	34785	2.016	1.3987	3.461	108	.0005	5.416	855.9	41.59	1.71	835.5
3000.00	0.00	290	34416	2.016	1.4052	3.418	85	.0004	6.467	869.1	89.05	1.74	854.5
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	2400	42627	2.007	1.2517	5.399	355	0.0023					
1.83	24.13	2119	41280	2.013	1.2877	4.559	327	.0017	1.000	608.1	1.00	0.70	342.3
3.00	14.70	1891	40300	2.015	1.3139	4.168	304	.0016	1.378	630.2	1.11	0.93	449.9
10.00	4.41	1398	38359	2.016	1.3529	3.780	250	.0012	2.140	707.8	2.02	1.25	609.4
30.00	1.47	1042	37046	2.016	1.3773	3.598	206	.0010	2.809	761.0	3.95	1.43	696.8
100.00	0.44	745	35995	2.016	1.3923	3.498	165	.0007	3.602	801.7	8.65	1.56	759.6
300.00	0.15	546	35301	2.016	1.3967	3.471	135	.0006	4.415	827.7	18.11	1.64	798.4
1000.00	0.04	388	34753	2.016	1.3986	3.459	106	.0005	5.428	847.8	41.35	1.70	827.7
3000.00	0.01	283	34393	2.016	1.4059	3.414	85	.0003	6.487	860.8	88.51	1.74	846.5
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	2400	42515	2.011	1.2718	4.863	355	0.0021					
1.83	80.09	2100	41167	2.015	1.3013	4.328	325	.0018	1.000	605.6	1.00	0.71	342.4
3.00	48.99	1870	40206	2.016	1.3206	4.079	302	.0016	1.377	627.2	1.11	0.93	448.3
10.00	14.70	1379	38289	2.016	1.3543	3.768	248	.0012	2.143	704.0	2.02	1.26	606.4
30.00	4.90	1027	36994	2.016	1.3783	3.591	204	.0009	2.813	756.7	3.94	1.44	693.1
100.00	1.47	734	35957	2.016	1.3927	3.498	164	.0007	3.607	797.1	8.63	1.56	755.4
300.00	0.49	538	35274	2.016	1.3959	3.469	133	.0006	4.421	822.8	18.05	1.64	793.8
1000.00	0.15	382	34733	2.016	1.3989	3.457	105	.0004	5.436	842.8	41.22	1.70	822.9
3000.00	0.05	279	34378	2.016	1.4054	3.411	84	.0003	6.490	855.6	88.23	1.74	841.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	2400	42458	2.013	1.2846	4.599	355	0.0020					
1.84	239.77	2090	41110	2.015	1.3040	4.224	324	.0017	1.000	604.3	1.00	0.71	342.5
3.00	146.96	1859	40158	2.016	1.3237	4.041	301	.0015	1.377	625.6	1.11	0.93	447.4
10.00	44.09	1370	38253	2.016	1.3550	3.763	246	.0012	2.144	702.0	2.01	1.26	604.9
30.00	14.70	1020	36967	2.016	1.3787	3.588	203	.0009	2.815	754.5	3.94	1.44	691.2
100.00	4.41	729	35938	2.016	1.3929	3.494	164	.0007	3.609	794.7	8.62	1.56	753.2
300.00	1.47	534	35260	2.016	1.3970	3.469	133	.0006	4.425	820.3	18.03	1.64	791.4
1000.00	0.44	379	34723	2.016	1.3990	3.456	105	.0004	5.439	840.2	41.17	1.70	820.4
3000.00	0.15	277	34371	2.016	1.4068	3.409	83	.0003	6.494	853.0	88.11	1.74	838.8
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	2400	42422	2.014	1.2934	4.420	355	0.0020					
1.84	798.30	2084	41075	2.016	1.3121	4.164	324	.0017	1.000	603.4	1.00	0.71	342.5
3.00	489.87	1852	40128	2.016	1.3255	4.020	300	.0015	1.377	624.6	1.11	0.93	446.8
10.00	146.96	1364	38231	2.016	1.3554	3.759	246	.0012	2.145	700.7	2.01	1.26	603.9
30.00	48.99	1015	36951	2.016	1.3790	3.588	203	.0009	2.816	753.1	3.93	1.44	690.0
100.00	14.70	726	35927	2.016	1.3930	3.494	163	.0007	3.611	793.2	8.61	1.56	751.8
300.00	4.90	532	35251	2.016	1.3971	3.468	132	.0006	4.426	818.8	18.01	1.64	789.9
1000.00	1.47	377	34717	2.016	1.3992	3.455	104	.0004	5.441	838.6	41.14	1.70	818.9
3000.00	0.49	275	34367	2.016	1.4069	3.409	83	.0003	6.497	851.3	88.04	1.74	837.7

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(i) Chamber temperature, 2600° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	2600	53411	1.697	1.1160	44.389	360	0.0164					
1.72	0.09	2506	51809	1.729	1.1132	42.610	353	.0155	1.000	708.9	1.00	0.65	373.4
3.00	0.05	2413	50248	1.762	1.1109	40.396	346	.0144	1.446	750.3	1.17	0.91	524.6
10.00	0.01	2226	47159	1.829	1.1077	34.350	331	.0118	2.161	880.2	2.47	1.28	737.6
30.00	0.00	2065	44639	1.888	1.1083	27.450	317	.0091	2.699	981.9	5.63	1.52	873.7
100.00	0.00	1886	42173	1.947	1.1176	18.650	301	.0060	3.232	1073.6	14.69	1.72	988.9
300.00	0.00	1698	40182	1.991	1.1544	10.219	283	.0032	3.678	1141.6	35.76	1.86	1072.9
1000.00	0.00	1382	38329	2.015	1.3145	4.213	248	.0013	4.104	1197.3	89.77	1.99	1145.6
3000.00	0.00	1036	37025	2.016	1.3775	3.597	205	.0009	4.828	1231.3	193.59	2.07	1194.1
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	2600	49178	1.817	1.1250	28.275	365	0.0108					
1.72	0.26	2491	47673	1.848	1.1239	25.886	357	.0097	1.000	683.8	1.00	0.65	361.8
3.00	0.15	2383	46236	1.879	1.1240	23.160	348	.0085	1.442	722.6	1.17	0.91	506.0
10.00	0.04	2150	43398	1.942	1.1319	16.343	328	.0057	2.155	844.2	2.43	1.28	709.2
30.00	0.01	1916	41136	1.988	1.1649	9.644	306	.0033	2.685	936.1	5.78	1.51	836.5
100.00	0.00	1563	39044	2.014	1.2949	4.480	269	.0015	3.186	1010.5	12.86	1.69	939.0
300.00	0.00	1183	37561	2.016	1.3670	3.673	224	.0011	3.817	1055.9	27.26	1.81	1005.4
1000.00	0.00	850	36364	2.016	1.3877	3.528	181	.0008	4.695	1090.5	62.17	1.90	1055.9
3000.00	0.00	624	35572	2.016	1.3949	3.482	148	.0007	5.633	1112.7	132.81	1.96	1088.1
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	2600	46501	1.901	1.1412	17.590	367	0.0069					
1.74	0.85	2464	45049	1.930	1.1448	15.117	358	.0058	1.000	665.9	1.00	0.66	355.4
3.00	0.49	2327	43713	1.957	1.1528	12.504	346	.0047	1.431	701.3	1.16	0.91	492.6
10.00	0.15	1991	41096	2.001	1.2075	6.888	314	.0025	2.128	811.3	2.32	1.27	685.8
30.00	0.05	1596	39141	2.015	1.3193	4.133	272	.0014	2.663	885.8	4.75	1.48	800.3
100.00	0.01	1169	37509	2.016	1.3686	3.660	222	.0010	3.377	941.3	10.50	1.64	884.6
300.00	0.00	864	36415	2.016	1.3870	3.533	183	.0008	4.131	976.4	22.00	1.74	936.8
1000.00	0.00	616	35544	2.016	1.3951	3.481	146	.0006	5.087	1003.5	50.12	1.81	976.4
3000.00	0.00	451	34971	2.016	1.3968	3.470	118	.0005	6.096	1020.9	107.29	1.86	1001.5
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	2600	45121	1.948	1.1623	11.992	371	0.0049					
1.76	2.51	2428	43684	1.973	1.1746	9.757	356	.0039	1.000	654.5	1.00	0.67	353.5
3.00	1.47	2256	42428	1.992	1.1965	7.682	340	.0030	1.414	686.3	1.14	0.92	484.1
10.00	0.44	1805	39996	2.014	1.2953	4.459	295	.0016	2.108	783.8	2.19	1.26	667.8
30.00	0.15	1376	38278	2.016	1.3533	3.778	247	.0012	2.730	848.1	4.33	1.46	771.5
100.00	0.04	995	36881	2.016	1.3803	3.578	200	.0009	3.488	897.2	9.53	1.60	846.8
300.00	0.01	733	35952	2.016	1.3928	3.495	164	.0007	4.270	928.4	19.09	1.69	893.3
1000.00	0.00	521	35215	2.016	1.3974	3.466	131	.0006	5.255	952.5	45.50	1.76	928.4
3000.00	0.00	381	34740	2.016	1.3989	3.457	105	.0004	6.288	968.0	97.51	1.80	950.8
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	2600	44265	1.978	1.1907	8.509	372	0.0036					
1.78	8.24	2382	42825	1.997	1.2151	6.749	352	.0028	1.000	645.3	1.00	0.68	354.0
3.00	4.90	2172	41649	2.008	1.2495	5.428	332	.0022	1.396	673.1	1.13	0.92	477.3
10.00	1.47	1660	39373	2.016	1.3301	3.992	279	.0014	2.121	761.6	2.10	1.26	652.5
30.00	0.49	1250	37805	2.016	1.3631	3.700	232	.0011	2.774	821.2	4.13	1.44	749.7
100.00	0.15	900	36540	2.016	1.3853	3.544	188	.0009	3.546	867.0	9.06	1.58	819.0
300.00	0.05	661	35701	2.016	1.3943	3.485	153	.0007	4.343	896.1	18.96	1.66	863.3
1000.00	0.01	470	35037	2.016	1.3970	3.469	122	.0005	5.343	918.6	43.37	1.73	896.1
3000.00	0.00	343	34600	2.016	1.4014	3.441	98	.0004	6.384	933.1	92.75	1.77	917.1
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	2600	43828	1.994	1.2180	6.727	373	0.0029					
1.80	24.44	2341	42339	2.007	1.2495	5.443	349	.0023	1.000	639.1	1.00	0.69	355.0
3.00	14.70	2110	41260	2.013	1.2826	4.656	326	.0019	1.386	664.4	1.12	0.92	472.6
10.00	4.41	1584	39074	2.016	1.3393	3.896	271	.0013	2.132	748.8	2.06	1.25	643.1
30.00	1.47	1189	37581	2.016	1.3675	3.668	224	.0011	2.792	806.4	4.04	1.44	737.3
100.00	0.44	854	36378	2.016	1.3875	3.530	181	.0008	3.571	850.6	8.87	1.57	805.1
300.00	0.15	627	35582	2.016	1.3949	3.482	148	.0007	4.375	878.8	18.57	1.65	847.3
1000.00	0.04	445	34952	2.016	1.3969	3.469	117	.0005	5.381	900.5	42.39	1.71	878.8
3000.00	0.01	325	34538	2.016	1.4028	3.433	94	.0004	6.425	914.6	90.86	1.75	899.1
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	2600	43557	2.004	1.2448	5.618	373	0.0025					
1.82	80.75	2307	42102	2.012	1.2762	4.777	346	.0022	1.000	634.4	1.00	0.70	355.7
3.00	48.99	2065	41025	2.015	1.3016	4.328	322	.0017	1.382	658.2	1.11	0.93	469.4
10.00	14.70	1539	38896	2.016	1.3435	3.857	266	.0013	2.139	740.4	2.04	1.26	636.8
30.00	4.90	1152	37447	2.016	1.3700	3.650	220	.0010	2.802	796.9	4.00	1.44	729.1
100.00	1.47	827	36282	2.016	1.3888	3.521	178	.0008	3.585	840.2	8.78	1.57	795.6
300.00	0.49	607	35512	2.016	1.3952	3.480	145	.0006	4.392	867.8	18.38	1.65	836.7
1000.00	0.15	431	34902	2.016	1.3971	3.468	115	.0005	5.401	889.1	41.97	1.71	867.8
3000.00	0.05	315	34502	2.016	1.4038	3.427	92	.0004	6.449	902.9	89.94	1.75	887.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	2600	43418	2.009	1.2638	5.052	373	0.0023					
1.83	241.13	2286	41963	2.014	1.2905	4.490	344	.0019	1.000	631.7	1.00	0.71	355.9
3.00	146.96	2041	40906	2.015	1.3101	4.201	319	.0017	1.381	654.8	1.11	0.93	467.5
10.00	44.09	1516	38807	2.016	1.3453	3.841	263	.0013	2.142	736.0	2.03	1.26	633.6
30.00	14.70	1134	37381	2.016	1.3712	3.641	218	.0010	2.807	791.9	3.99	1.44	724.8
100.00	4.41	813	36234	2.016	1.3894	3.517	176	.0008	3.593	834.7	8.74	1.57	790.6
300.00	1.47	596	35477	2.016	1.3954	3.478	143	.0006	4.400	862.0	18.20	1.65	831.3
1000.00	0.44	424	34877	2.016	1.3973	3.467	113	.0005	5.410	883.1	41.79	1.71	862.1
3000.00	0.15	309	34484	2.016	1.4042	3.425	90	.0004	6.459	896.8	89.55	1.75	881.7
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	2600	43333	2.012	1.2782	4.703	374	0.0022					
1.83	801.56	2273	41876	2.015	1.2995	4.333	343	.0019	1.000	629.9	1.00	0.71	356.0
3.00	489.87	2025	40834	2.016	1.3148	4.135	318	.0017	1.380	652.6	1.11	0.93	466.9
10.00	146.96	1501	38753	2.016	1.3464	3.832	262	.0013	2.144	733.3	2.03	1.26	631.3
30.00	48.99	1123	37340	2.016	1.3720	3.636	216	.0010	2.809	788.8	3.98	1.44	722.1
100.00	14.70	805	36205	2.016	1.3897	3.515	175	.0008	3.595	831.4	8.72	1.57	787.5
300.00	4.90	590	35456	2.016	1.3956	3.477	142	.0006	4.405	858.5	18.26	1.65	827.0
1000.00	1.47	419	34862	2.016	1.3973	3.466	112	.0005	5.416	879.5	41.70	1.71	858.5
3000.00	0.49	306	34472	2.016	1.4044	3.423	90	.0004	6.465	893.0	89.33	1.75	878.0

E-694

E-692

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(j) Chamber temperature, 2800° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	2800	64601	1.464	1.1197	66.447	363	0.0247					
1.72	0.09	2701	62599	1.495	1.1155	57.354	357	.0246	1.000	791.6	1.00	0.65	417.4
3.00	0.05	2606	60656	1.526	1.1116	67.769	351	.0243	1.446	837.8	1.17	0.91	585.9
10.00	0.01	2420	56805	1.594	1.1044	66.945	338	.0231	2.163	983.0	2.47	1.28	823.6
30.00	0.00	2269	53654	1.654	1.0991	64.241	327	.0215	2.709	1097.5	5.66	1.52	976.0
100.00	0.00	2120	50541	1.719	1.0945	59.277	315	.0191	3.237	1202.5	14.98	1.73	1106.1
300.00	0.00	1996	47970	1.776	1.0915	53.037	306	.0166	3.694	1283.7	37.65	1.89	1203.0
1000.00	0.00	1868	45412	1.837	1.0900	44.461	296	.0135	4.174	1360.2	105.71	2.01	1292.2
3000.00	0.00	1755	43290	1.891	1.0912	35.192	285	.0104	4.602	1422.7	274.78	2.12	1361.7
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	2800	56538	1.640	1.1228	45.965	374	0.0177					
1.72	0.26	2694	54748	1.673	1.1192	44.876	367	.0170	1.000	747.3	1.00	0.65	394.7
3.00	0.15	2591	53023	1.707	1.1160	43.362	359	.0161	1.445	795.4	1.17	0.91	555.0
10.00	0.04	2387	49695	1.777	1.1107	38.744	344	.0138	2.162	925.2	2.46	1.28	776.7
30.00	0.01	2216	46826	1.838	1.1083	33.031	330	.0113	2.705	1032.6	5.60	1.51	919.0
100.00	0.00	2038	44106	1.902	1.1100	25.300	315	.0083	3.244	1120.1	14.66	1.71	1040.1
300.00	0.00	1871	41892	1.954	1.1217	17.191	300	.0055	3.704	1200.3	41.51	1.82	1124.4
1000.00	0.00	1549	37756	2.000	1.1772	8.250	278	.0026	4.172	1267.4	97.13	1.92	1208.4
3000.00	0.00	1342	38126	2.015	1.3349	3.973	242	.0012	4.583	1310.3	223.51	2.02	1265.7
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	2800	51037	1.788	1.1315	28.450	352	0.0113					
1.73	0.85	2677	49387	1.821	1.1294	26.493	373	.0103	1.000	714.5	1.00	0.65	378.0
3.00	0.49	2559	47825	1.853	1.1281	24.209	363	.0092	1.441	754.5	1.16	0.91	528.7
10.00	0.15	2310	44737	1.919	1.1312	18.244	343	.0066	2.158	881.0	2.42	1.28	740.4
30.00	0.05	2076	42274	1.971	1.1496	11.989	321	.0042	2.699	977.5	5.36	1.51	877.5
100.00	0.01	1758	39959	2.008	1.2342	5.804	290	.0020	3.213	1058.8	13.29	1.69	981.8
300.00	0.00	1370	38260	2.016	1.3482	3.829	246	.0012	3.746	1110.1	28.83	1.80	1054.4
1000.00	0.00	992	36868	2.016	1.3804	3.577	200	.0009	4.582	1148.7	66.07	1.91	1110.4
3000.00	0.00	730	35947	2.016	1.3929	3.495	154	.0007	5.489	1173.4	141.31	1.98	1145.1
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	2800	48123	1.877	1.1449	18.490	386	0.0076					
1.74	2.54	2653	46539	1.908	1.1451	16.349	374	.0066	1.000	695.1	1.00	0.65	371.0
3.00	1.47	2510	45083	1.936	1.1502	14.030	362	.0055	1.432	732.2	1.16	0.91	514.3
10.00	0.44	2178	42227	1.988	1.1823	8.587	332	.0032	2.141	848.8	2.34	1.27	716.6
30.00	0.15	1806	40041	2.012	1.2752	4.816	295	.0017	2.666	931.1	4.92	1.49	838.6
100.00	0.04	1348	38173	2.016	1.3547	3.767	244	.0012	3.325	992.6	11.03	1.65	930.5
300.00	0.01	1003	36907	2.016	1.3798	3.581	201	.0009	4.055	1031.4	23.19	1.75	987.0
1000.00	0.00	717	35896	2.016	1.3934	3.491	162	.0007	4.985	1061.3	52.90	1.83	1031.5
3000.00	0.00	525	35229	2.016	1.3972	3.467	131	.0006	5.972	1080.5	119.21	1.88	1066.5
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	2800	46304	1.937	1.1662	12.134	389	0.0052					
1.76	8.36	2615	44749	1.963	1.1749	10.165	373	.0042	1.000	680.8	1.00	0.67	367.8
3.00	4.90	2433	43389	1.984	1.1909	8.266	357	.0034	1.417	714.1	1.14	0.92	503.6
10.00	1.47	1976	40743	2.012	1.2722	4.873	313	.0019	2.116	817.7	2.32	1.26	695.6
30.00	0.49	1525	38848	2.016	1.3613	3.883	264	.0013	2.719	886.7	4.49	1.56	805.4
100.00	0.15	1110	37295	2.016	1.3728	3.630	215	.0010	3.463	939.2	9.77	1.61	885.4
300.00	0.05	820	36257	2.016	1.3891	3.519	177	.0008	4.231	972.6	20.50	1.70	935.0
1000.00	0.01	583	35432	2.016	1.3957	3.477	141	.0006	5.205	998.4	46.77	1.77	972.6
3000.00	0.00	427	34889	2.016	1.3972	3.467	114	.0005	6.230	1015.0	100.22	1.81	996.2
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	2800	45369	1.970	1.1904	8.847	390	0.0039					
1.78	24.80	2572	43818	1.990	1.2084	7.232	370	.0031	1.000	671.5	1.00	0.68	367.4
3.00	14.70	2355	42535	2.003	1.2352	5.908	350	.0025	1.402	701.3	1.13	0.92	496.4
10.00	4.41	1827	40046	2.015	1.3148	4.165	297	.0016	2.120	795.7	2.13	1.26	680.6
30.00	1.47	1386	38314	2.016	1.3535	3.775	248	.0012	2.769	859.4	4.20	1.46	783.2
100.00	0.44	1003	36906	2.016	1.3798	3.581	201	.0009	3.523	908.2	9.26	1.59	858.1
300.00	0.15	738	35971	2.016	1.3926	3.497	165	.0007	4.307	939.3	19.49	1.67	904.3
1000.00	0.04	525	35226	2.016	1.3972	3.468	131	.0006	5.297	963.3	44.31	1.74	939.4
3000.00	0.01	384	34740	2.016	1.3988	3.457	106	.0005	6.336	978.8	95.01	1.78	961.7
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	2800	44791	1.990	1.2184	6.810	391	0.0031					
1.80	81.65	2526	43234	2.004	1.2436	5.648	366	.0025	1.000	664.1	1.00	0.69	368.1
3.00	48.99	2283	42018	2.011	1.2722	4.861	343	.0020	1.390	691.0	1.19	0.92	491.3
10.00	14.70	1729	39642	2.016	1.3295	3.988	287	.0015	2.132	780.2	2.07	1.26	669.4
30.00	4.90	1304	38008	2.016	1.3593	3.729	238	.0011	2.786	841.1	4.10	1.44	768.3
100.00	1.47	941	36686	2.016	1.3832	3.558	193	.0009	3.555	887.9	9.01	1.58	839.8
300.00	0.49	692	35808	2.016	1.3941	3.487	158	.0007	4.348	917.7	18.88	1.66	884.1
1000.00	0.15	492	35113	2.016	1.3976	3.465	126	.0005	5.347	940.7	43.11	1.72	917.7
3000.00	0.05	360	34656	2.016	1.4002	3.449	101	.0004	6.391	955.5	92.44	1.76	939.1
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	2800	44495	2.001	1.2415	5.766	391	0.0027					
1.81	242.99	2493	42933	2.010	1.2674	4.963	363	.0022	1.000	659.5	1.00	0.70	368.5
3.00	146.96	2238	41759	2.014	1.2913	4.481	339	.0019	1.385	684.8	1.11	0.92	487.8
10.00	44.09	1679	39444	2.016	1.3346	3.936	282	.0014	2.139	771.6	2.05	1.26	663.0
30.00	14.70	1264	37858	2.016	1.3622	3.707	234	.0011	2.796	831.3	4.05	1.44	759.8
100.00	4.41	911	36578	2.016	1.3847	3.548	189	.0009	3.569	877.1	8.91	1.57	830.0
300.00	1.47	669	35729	2.016	1.3943	3.486	155	.0007	4.367	906.2	18.66	1.65	877.4
1000.00	0.44	475	35056	2.016	1.3971	3.468	123	.0005	5.370	928.7	42.61	1.72	906.3
3000.00	0.15	348	34614	2.016	1.4011	3.443	98	.0004	6.416	943.3	91.38	1.76	925.5
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	2800	44312	2.008	1.2611	5.120	392	0.0024					
1.82	805.74	2468	42748	2.013	1.2837	4.598	361	.0021	1.000	656.3	1.00	0.70	368.9
3.00	489.87	2207	41601	2.015	1.3020	4.300	336	.0018	1.383	680.7	1.11	0.93	485.7
10.00	146.96	1649	39324	2.016	1.3373	3.911	278	.0014	2.143	766.2	2.04	1.26	658.8
30.00	48.99	1240	37768	2.016	1.3640	3.694	231	.0011	2.802	825.1	4.03	1.44	754.6
100.00	14.70	892	36513	2.016	1.3856	3.542	187	.0008	3.578	870.3	8.86	1.57	823.8
300.00	4.90	655	35681	2.016	1.3944	3.485	152	.0007	4.378	899.0	18.55	1.65	866.6
1000.00	1.47	466	35023	2.016	1.3969	3.469	121	.0005	5.384	921.3	42.76	1.72	899.1
3000.00	0.49	340	34590	2.016	1.4015	3.441	97	.0004	6.431	935.7	90.83	1.75	919.8

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(k) Chamber temperature, 3000° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	3000	78633	1.246	1.1315	68.633	363	0.0256					
1.73	0.09	2885	76103	1.275	1.1251	74.170	356	.0271	1.000	886.2	1.00	0.65	469.2
3.00	0.05	2778	73689	1.304	1.1195	79.103	350	.0283	1.444	936.9	1.17	0.91	655.9
10.00	0.01	2573	68898	1.366	1.1095	87.511	338	.0301	2.166	1097.2	2.45	1.28	920.4
30.00	0.00	2412	64998	1.423	1.1022	92.504	327	.0308	2.710	1223.8	5.61	1.51	1089.2
100.00	0.00	2257	61156	1.484	1.0956	95.209	317	.0307	3.249	1339.8	14.82	1.71	1233.2
300.00	0.00	2132	57986	1.539	1.0906	95.312	309	.0299	3.708	1429.7	37.26	1.86	1340.3
1000.00	0.00	2008	54829	1.598	1.0859	93.002	300	.0283	4.190	1514.7	104.93	2.00	1439.2
3000.00	0.00	1906	52200	1.651	1.0823	88.826	292	.0263	4.615	1582.4	274.34	2.11	1516.6
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	3000	67479	1.427	1.1286	61.947	377	0.0240					
1.72	0.26	2886	65270	1.458	1.1235	63.473	370	.0241	1.000	838.6	1.00	0.65	438.4
3.00	0.15	2778	63157	1.491	1.1189	64.502	363	.0240	1.444	876.0	1.17	0.91	613.2
10.00	0.04	2568	58966	1.560	1.1104	64.984	349	.0232	2.165	1026.1	2.45	1.28	860.7
30.00	0.01	2401	55557	1.621	1.1047	63.427	338	.0219	2.709	1144.2	5.60	1.51	1018.5
100.00	0.00	2237	52205	1.688	1.0987	59.666	326	.0199	3.249	1252.2	14.77	1.71	1152.8
300.00	0.00	2101	49448	1.747	1.0949	54.477	315	.0176	3.712	1335.6	37.02	1.86	1252.6
1000.00	0.00	1964	46714	1.809	1.0924	46.996	304	.0147	4.199	1414.0	103.74	2.00	1344.2
3000.00	0.00	1845	44451	1.865	1.0920	38.660	294	.0117	4.632	1476.0	269.40	2.10	1416.5
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	3000	58106	1.624	1.1314	42.532	390	0.0171					
1.73	0.85	2879	56163	1.658	1.1270	41.779	382	.0165	1.000	776.0	1.00	0.65	411.2
3.00	0.49	2762	54316	1.692	1.1232	40.621	374	.0157	1.443	820.0	1.17	0.91	574.3
10.00	0.15	2532	50654	1.765	1.1168	36.775	357	.0136	2.164	959.3	2.44	1.28	805.2
30.00	0.05	2342	47694	1.828	1.1135	31.771	342	.0113	2.710	1068.2	5.54	1.51	951.9
100.00	0.01	2146	44809	1.893	1.1142	24.809	326	.0085	3.256	1165.8	14.46	1.71	1075.7
300.00	0.00	1966	42471	1.948	1.1235	17.366	310	.0057	3.726	1241.2	35.63	1.85	1166.4
1000.00	0.00	1737	40219	1.995	1.1696	8.916	287	.0029	4.205	1307.9	95.74	1.98	1247.6
3000.00	0.00	1424	38488	2.015	1.3152	4.201	253	.0013	4.609	1353.3	222.58	2.07	1305.5
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	3000	52704	1.765	1.1387	27.757	398	0.0116					
1.73	2.55	2862	50909	1.799	1.1356	25.165	388	.0106	1.000	743.2	1.00	0.66	395.2
3.00	1.47	2731	49228	1.833	1.1335	24.256	378	.0096	1.439	784.2	1.16	0.91	548.9
10.00	0.44	2460	45903	1.901	1.1337	19.062	356	.0072	2.160	914.7	2.41	1.28	769.3
30.00	0.15	2215	43256	1.956	1.1455	13.363	335	.0049	2.707	1014.7	5.37	1.50	906.7
100.00	0.04	1907	40757	2.001	1.2020	7.098	305	.0025	3.239	1100.4	13.41	1.69	1019.6
300.00	0.01	1530	38882	2.015	1.3235	4.087	265	.0014	3.721	1156.5	29.78	1.82	1086.7
1000.00	0.00	1117	37320	2.016	1.3722	3.634	216	.0010	4.512	1198.6	68.71	1.92	1157.0
3000.00	0.00	825	36275	2.016	1.3868	3.521	177	.0008	5.394	1225.2	147.28	1.98	1195.6
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	3000	49234	1.870	1.1529	17.466	403	0.0075					
1.74	8.43	2834	47525	1.901	1.1532	15.632	390	.0066	1.000	719.8	1.00	0.66	385.5
3.00	4.90	2676	45974	1.930	1.1562	13.625	377	.0056	1.431	757.6	1.15	0.91	532.5
10.00	1.47	2316	42920	1.983	1.1826	8.766	346	.0034	2.145	877.4	2.33	1.27	741.2
30.00	0.49	1932	40593	2.010	1.2614	5.112	308	.0019	2.679	963.9	4.93	1.49	863.1
100.00	0.15	1456	38583	2.016	1.3460	3.841	256	.0013	3.320	1027.6	11.13	1.66	963.7
300.00	0.05	1088	37213	2.016	1.3743	3.619	212	.0010	4.039	1068.3	23.48	1.76	1022.7
1000.00	0.01	779	36114	2.016	1.3909	3.508	171	.0008	4.956	1099.2	53.66	1.83	1069.4
3000.00	0.00	571	35389	2.016	1.3960	3.475	139	.0006	5.936	1119.9	114.89	1.88	1097.6
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	3000	47434	1.929	1.1717	11.988	406	0.0053					
1.76	25.07	2799	45760	1.956	1.1778	10.271	389	.0044	1.000	705.7	1.00	0.67	381.7
3.00	14.70	2604	44302	1.978	1.1900	8.571	373	.0036	1.418	740.1	1.14	0.92	522.0
10.00	4.41	2133	41455	2.009	1.2562	5.245	329	.0021	2.124	846.6	2.23	1.27	721.3
30.00	1.47	1665	39396	2.016	1.3294	3.999	280	.0014	2.714	921.7	4.49	1.47	834.3
100.00	0.44	1220	37695	2.016	1.3653	3.684	225	.0011	3.445	977.4	8.97	1.62	920.6
300.00	0.15	903	36552	2.016	1.3851	3.545	185	.0009	4.201	1012.9	20.96	1.71	973.1
1000.00	0.04	644	35642	2.016	1.3946	3.484	151	.0007	5.169	1040.2	47.84	1.78	1013.9
3000.00	0.01	471	35043	2.016	1.3970	3.468	122	.0005	6.178	1057.8	102.51	1.82	1038.4
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	3000	46318	1.967	1.1967	8.563	408	0.0040					
1.78	82.58	2750	44653	1.987	1.2115	7.175	386	.0032	1.000	694.9	1.00	0.68	380.7
3.00	48.99	2518	43282	2.001	1.2337	6.003	366	.0026	1.403	725.6	1.12	0.92	514.0
10.00	14.70	1965	40613	2.015	1.3048	4.291	312	.0017	2.124	824.2	2.14	1.26	704.6
30.00	4.90	1499	38744	2.016	1.3458	3.838	261	.0013	2.760	891.0	4.34	1.45	811.8
100.00	1.47	1089	37219	2.016	1.3742	3.620	212	.0010	3.512	942.3	8.36	1.59	889.8
300.00	0.49	804	36201	2.016	1.3898	3.515	174	.0008	4.287	975.0	19.70	1.68	933.3
1000.00	0.15	573	35392	2.016	1.3960	3.475	139	.0006	5.269	1000.2	44.99	1.74	975.1
3000.00	0.05	419	34860	2.016	1.3973	3.466	112	.0005	6.304	1016.5	96.45	1.79	998.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	3000	45746	1.987	1.2205	6.803	409	0.0032					
1.80	245.21	2708	44078	2.002	1.2409	5.771	383	.0026	1.000	687.9	1.00	0.69	380.9
3.00	146.96	2452	42770	2.010	1.2650	5.024	360	.0022	1.393	716.1	1.12	0.92	508.9
10.00	44.09	1870	40208	2.016	1.3203	4.084	302	.0016	2.133	809.7	2.09	1.26	694.2
30.00	14.70	1418	38436	2.016	1.3516	3.789	252	.0012	2.782	873.8	4.14	1.44	797.6
100.00	4.41	1027	36995	2.016	1.3783	3.592	204	.0009	3.541	923.1	8.14	1.58	872.6
300.00	1.47	757	36036	2.016	1.3918	3.502	168	.0007	4.325	954.5	19.18	1.67	919.3
1000.00	0.44	538	35275	2.016	1.3968	3.470	134	.0006	5.316	978.7	43.81	1.73	954.5
3000.00	0.15	394	34774	2.016	1.3983	3.461	105	.0005	6.358	994.4	93.94	1.77	977.1
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	3000	45393	2.000	1.2435	5.715	409	0.0028					
1.81	810.77	2672	43721	2.009	1.2649	6.019	382	.0023	1.000	683.8	1.00	0.70	381.3
3.00	489.87	2401	42459	2.013	1.2854	4.572	355	.0020	1.388	709.3	1.12	0.92	505.9
10.00	146.96	1812	39968	2.016	1.3269	4.008	296	.0015	2.140	800.1	2.07	1.26	687.0
30.00	48.99	1370	38254	2.016	1.3549	3.763	246	.0012	2.793	862.7	4.09	1.44	788.1
100.00	14.70	991	36863	2.016	1.3805	3.576	200	.0009	3.557	910.8	8.03	1.58	861.5
300.00	4.90	729	35939	2.016	1.3929	3.494	164	.0007	4.346	941.4	18.92	1.66	907.0
1000.00	1.47	518	35206	2.016	1.3974	3.466	130	.0006	5.342	965.1	43.20	1.72	941.5
3000.00	0.49	379	34724	2.016	1.3990	3.456	105	.0004	6.388	980.4	92.66	1.76	963.5

TABLE I. - Continued. THEORETICAL PERFROMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(l) Chamber temperature, 3200° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	3200	90252	1.112	1.1554	45.454	365	0.0174					
1.74	0.08	3052	87210	1.138	1.1423	55.444	357	.0205	1.000	964.9	1.00	0.66	514.5
3.00	0.05	2923	84389	1.165	1.1327	64.734	350	.0233	1.441	1017.9	1.16	0.91	714.2
10.00	0.01	2687	78776	1.223	1.1175	82.620	336	.0284	2.170	1189.3	2.43	1.28	999.3
30.00	0.00	2508	74242	1.276	1.1076	95.756	326	.0318	2.721	1324.2	5.52	1.51	1180.3
100.00	0.00	2342	69798	1.334	1.0993	106.725	315	.0342	3.266	1447.0	14.55	1.71	1334.1
300.00	0.00	2209	66146	1.385	1.0931	113.756	307	.0354	3.731	1543.5	36.53	1.85	1448.3
1000.00	0.00	2081	62516	1.442	1.0875	118.399	299	.0358	4.217	1633.8	102.75	1.99	1553.5
3000.00	0.00	1976	59499	1.492	1.0831	120.020	291	.0354	4.646	1705.8	268.54	2.09	1635.8
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	3200	80142	1.238	1.1413	60.878	378	0.0237					
1.73	0.25	3067	77417	1.268	1.1328	66.362	370	.0252	1.000	916.4	1.00	0.66	486.9
3.00	0.15	2946	74855	1.298	1.1274	71.214	363	.0265	1.442	967.6	1.16	0.91	678.7
10.00	0.04	2715	69768	1.363	1.1160	79.586	349	.0284	2.167	1131.4	2.44	1.28	950.1
30.00	0.01	2535	65653	1.421	1.1077	84.618	338	.0291	2.716	1260.2	5.54	1.51	1122.8
100.00	0.00	2364	61619	1.484	1.1004	87.427	327	.0291	3.261	1378.0	14.59	1.71	1269.5
300.00	0.00	2226	58357	1.541	1.0948	87.669	317	.0283	3.727	1469.0	36.58	1.85	1378.4
1000.00	0.00	2091	55022	1.602	1.0897	85.558	308	.0268	4.216	1554.8	102.70	1.99	1478.4
3000.00	0.00	1979	52295	1.657	1.0859	81.600	300	.0249	4.649	1622.9	267.82	2.09	1556.6
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	3200	67928	1.435	1.1375	54.575	394	0.0221					
1.73	0.85	3068	65578	1.469	1.1317	55.986	386	.0222	1.000	851.6	1.00	0.65	452.1
3.00	0.49	2946	63363	1.502	1.1265	56.917	378	.0221	1.442	899.3	1.16	0.91	630.2
10.00	0.15	2709	58966	1.574	1.1170	57.268	362	.0213	2.166	1051.6	2.44	1.28	883.0
30.00	0.05	2521	55412	1.638	1.1101	55.685	349	.0199	2.715	1171.1	5.53	1.51	1043.6
100.00	0.01	2338	51937	1.706	1.1042	51.981	336	.0179	3.261	1280.0	14.53	1.71	1179.6
300.00	0.00	2187	49094	1.767	1.1009	46.915	325	.0156	3.731	1363.7	36.29	1.85	1280.1
1000.00	0.00	2034	46288	1.831	1.0980	39.649	312	.0128	4.226	1442.2	101.26	1.99	1372.2
3000.00	0.00	1900	43979	1.887	1.0988	31.595	301	.0099	4.668	1503.8	261.78	2.09	1443.5
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	3200	59354	1.616	1.1399	38.848	406	0.0164					
1.73	2.55	3060	57264	1.651	1.1349	38.331	397	.0158	1.000	802.1	1.00	0.66	426.4
3.00	1.47	2930	55304	1.686	1.1305	37.429	388	.0150	1.440	846.7	1.16	0.91	593.6
10.00	0.44	2672	51418	1.760	1.1231	34.153	369	.0131	2.165	988.9	2.42	1.28	831.0
30.00	0.15	2461	48295	1.825	1.1191	29.696	353	.0109	2.716	1099.8	5.47	1.51	981.0
100.00	0.04	2245	45267	1.892	1.1194	23.353	335	.0082	3.267	1199.8	14.24	1.70	1107.1
300.00	0.01	2049	42824	1.947	1.1286	16.490	318	.0056	3.743	1275.1	34.90	1.84	1199.3
1000.00	0.00	1801	40483	1.995	1.1742	8.666	294	.0029	4.233	1342.3	93.64	1.97	1281.4
3000.00	0.00	1476	38689	2.015	1.3114	4.248	259	.0014	4.653	1388.2	217.77	2.06	1340.9
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	3200	53410	1.771	1.1482	24.566	415	0.0107					
1.74	8.46	3041	51494	1.806	1.1446	23.194	404	.0099	1.000	764.9	1.00	0.66	408.2
3.00	4.90	2892	49728	1.839	1.1427	21.535	392	.0089	1.436	806.2	1.16	0.91	566.0
10.00	1.47	2584	46232	1.908	1.1425	16.917	368	.0067	2.160	938.4	2.39	1.28	790.3
30.00	0.49	2307	43472	1.962	1.1563	11.826	344	.0045	2.712	1039.2	5.29	1.50	929.9
100.00	0.15	1960	40891	2.004	1.2187	6.396	311	.0023	3.251	1124.7	13.07	1.68	1043.7
300.00	0.05	1556	38977	2.015	1.3279	4.031	268	.0014	3.764	1180.2	28.83	1.81	1120.6
1000.00	0.01	1136	37389	2.016	1.3710	3.642	218	.0010	4.568	1222.0	66.60	1.91	1180.7
3000.00	0.00	839	36326	2.016	1.3882	3.525	179	.0008	5.454	1248.7	142.94	1.97	1219.7
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	3200	50242	1.866	1.1614	16.289	420	0.0074					
1.75	25.23	3013	48411	1.898	1.1608	14.720	406	.0065	1.000	743.0	1.00	0.66	399.1
3.00	14.70	2837	46769	1.927	1.1630	12.987	392	.0055	1.429	781.3	1.15	0.91	549.7
10.00	4.41	2445	43534	1.981	1.1860	8.678	358	.0035	2.147	903.7	2.32	1.27	764.0
30.00	1.47	2042	41075	2.009	1.2546	5.279	319	.0020	2.690	991.5	4.91	1.49	893.1
100.00	0.44	1550	38943	2.016	1.3386	3.909	267	.0013	3.324	1058.6	11.15	1.65	991.6
300.00	0.15	1162	37482	2.016	1.3693	3.655	221	.0010	4.034	1101.0	23.60	1.75	1053.7
1000.00	0.04	834	36307	2.016	1.3884	3.523	179	.0008	4.941	1133.6	54.05	1.83	1101.1
3000.00	0.01	612	35530	2.016	1.3951	3.480	146	.0006	5.913	1154.6	115.78	1.88	1131.4
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	3200	48261	1.931	1.1816	10.977	423	0.0051					
1.76	83.31	2970	46471	1.957	1.1871	9.529	405	.0043	1.000	727.1	1.00	0.67	394.6
3.00	48.99	2756	44936	1.978	1.1983	8.095	387	.0036	1.416	761.8	1.14	0.92	537.9
10.00	14.70	2246	41932	2.009	1.2571	5.226	340	.0022	2.129	872.4	2.22	1.27	742.1
30.00	4.90	1758	39762	2.016	1.3237	4.057	290	.0015	2.722	947.6	4.48	1.47	859.9
100.00	1.47	1292	37963	2.016	1.3601	3.723	237	.0011	3.448	1005.1	9.98	1.61	946.6
300.00	0.49	959	36751	2.016	1.3822	3.565	196	.0009	4.197	1041.8	21.02	1.71	1000.7
1000.00	0.15	685	35784	2.016	1.3941	3.487	157	.0007	5.150	1070.1	48.05	1.78	1041.9
3000.00	0.05	501	35147	2.016	1.3980	3.462	127	.0006	6.161	1088.3	102.97	1.82	1068.2
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	3200	47742	1.966	1.2035	8.225	425	0.0040					
1.78	247.40	2926	45463	1.986	1.2157	7.044	402	.0033	1.000	717.2	1.00	0.68	393.5
3.00	146.96	2678	44008	2.000	1.2343	6.021	380	.0027	1.403	748.7	1.13	0.92	530.5
10.00	44.09	2097	41164	2.014	1.2970	4.399	325	.0018	2.129	851.0	2.14	1.26	727.2
30.00	14.70	1608	39165	2.016	1.3387	3.900	274	.0014	2.759	920.6	4.27	1.45	838.4
100.00	4.41	1174	37525	2.016	1.3685	3.660	223	.0010	3.504	974.3	9.49	1.59	919.5
300.00	1.47	868	36427	2.016	1.3868	3.534	183	.0008	4.270	1008.5	19.95	1.68	970.1
1000.00	0.44	618	35553	2.016	1.3950	3.481	147	.0006	5.244	1034.8	45.58	1.75	1008.5
3000.00	0.15	453	34978	2.016	1.3969	3.470	119	.0005	6.274	1051.8	97.72	1.79	1033.0
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	3200	46612	1.988	1.2273	6.518	426	0.0033					
1.80	816.54	2881	44833	2.002	1.2443	5.669	399	.0027	1.000	709.7	1.00	0.69	393.5
3.00	489.87	2607	43444	2.009	1.2645	5.032	374	.0023	1.394	738.7	1.12	0.92	525.0
10.00	146.96	1995	40716	2.016	1.3137	4.154	315	.0017	2.136	835.8	2.09	1.26	716.3
30.00	48.99	1519	38822	2.016	1.3451	3.843	264	.0013	2.781	902.5	4.17	1.45	823.3
100.00	14.70	1105	37275	2.016	1.3732	3.627	214	.0010	3.534	953.9	9.23	1.58	901.4
300.00	4.90	816	36242	2.016	1.3893	3.518	176	.0008	4.309	986.7	19.40	1.67	949.9
1000.00	1.47	581	35421	2.016	1.3958	3.476	141	.0006	5.294	1012.0	44.32	1.73	986.8
3000.00	0.49	425	34881	2.016	1.3972	3.467	114	.0005	6.332	1028.3	95.05	1.78	1010.3

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(m) Chamber temperature, 3400° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, cal/(g)(°K)	Absolute viscosity, μ, micropoises	Thermal conductivity, k, cal/(sec)(°K)(cm)	Mach number, M	Specific impulse in vacuum, I_{vac}, (lb)(sec)/lb	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, (lb)(sec)/lb
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	3400	96980	1.051	1.2040	23.673	373	0.0097					
1.75	0.08	3190	93537	1.075	1.1683	35.410	360	.0136	1.000	1015.9	1.00	0.67	547.4
3.00	0.05	3032	90476	1.100	1.1491	46.721	351	.0172	1.438	1069.1	1.15	0.92	752.4
10.00	0.01	2759	84345	1.156	1.1252	70.154	336	.0242	2.176	1245.3	2.40	1.28	1048.5
30.00	0.00	2564	79431	1.207	1.1129	88.422	325	.0293	2.734	1384.4	5.43	1.51	1235.7
100.00	0.00	2387	74636	1.262	1.1023	104.750	314	.0335	3.284	1511.6	14.30	1.70	1394.4
300.00	0.00	2249	70706	1.312	1.0953	116.343	306	.0361	3.754	1610.0	35.84	1.84	1512.0
1000.00	0.00	2116	66810	1.367	1.0890	125.606	297	.0378	4.244	1702.9	100.73	1.98	1620.3
3000.00	0.00	2008	63575	1.416	1.0842	131.106	290	.0385	4.676	1776.8	263.14	2.08	1704.9
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	3400	90608	1.119	1.1647	42.348	380	0.0169					
1.74	0.25	3233	87386	1.147	1.1506	51.474	371	.0199	1.000	989.8	1.00	0.66	529.5
3.00	0.15	3090	84440	1.174	1.1402	59.858	363	.0225	1.439	1043.1	1.16	0.91	732.6
10.00	0.04	2826	78572	1.235	1.1237	76.010	348	.0271	2.171	1216.7	2.41	1.28	1023.4
30.00	0.01	2629	73860	1.291	1.1129	87.736	337	.0301	2.727	1353.1	5.46	1.51	1207.7
100.00	0.00	2446	69265	1.350	1.1039	97.337	326	.0322	3.278	1477.7	14.34	1.70	1362.8
300.00	0.00	2301	65904	1.404	1.0972	103.268	316	.0332	3.749	1573.8	35.89	1.85	1478.0
1000.00	0.00	2161	61782	1.463	1.0912	106.854	307	.0333	4.242	1664.4	100.67	1.98	1583.7
3000.00	0.00	2061	58698	1.515	1.0865	107.637	299	.0327	4.678	1736.4	262.46	2.08	1666.3
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	3400	79156	1.266	1.1495	55.190	395	0.0226					
1.74	0.85	3250	76315	1.297	1.1415	59.715	387	.0238	1.000	932.7	1.00	0.66	497.2
3.00	0.49	3115	73679	1.329	1.1345	63.621	379	.0248	1.440	983.9	1.16	0.91	690.3
10.00	0.15	2856	68443	1.397	1.1222	70.159	363	.0261	2.168	1148.6	2.42	1.28	965.5
30.00	0.05	2658	64230	1.458	1.1134	73.717	351	.0264	2.722	1277.8	5.48	1.51	1139.6
100.00	0.01	2466	60124	1.524	1.1054	75.132	338	.0259	3.273	1395.6	14.38	1.70	1286.9
300.00	0.00	2314	56767	1.584	1.0994	74.282	328	.0248	3.748	1486.2	35.99	1.85	1395.7
1000.00	0.00	2165	53452	1.648	1.0941	71.151	317	.0230	4.242	1571.5	100.49	1.98	1495.5
3000.00	0.00	2042	50713	1.705	1.0903	66.416	308	.0209	4.682	1639.0	261.24	2.08	1573.7
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	3400	68129	1.449	1.1463	48.126	411	0.0204					
1.73	2.54	3250	65649	1.484	1.1398	49.377	401	.0205	1.000	872.1	1.00	0.66	464.5
3.00	1.47	3113	63341	1.518	1.1341	50.160	393	.0203	1.440	920.0	1.16	0.91	645.4
10.00	0.44	2846	58762	1.592	1.1236	50.307	375	.0194	2.167	1074.0	2.42	1.28	902.8
30.00	0.15	2636	55082	1.658	1.1160	48.626	361	.0180	2.721	1194.4	5.47	1.51	1065.5
100.00	0.04	2422	51504	1.729	1.1098	44.909	345	.0160	3.274	1303.9	14.30	1.70	1202.7
300.00	0.01	2265	48592	1.791	1.1059	39.910	333	.0137	3.750	1387.7	35.58	1.84	1303.8
1000.00	0.00	2094	45734	1.857	1.1044	32.808	319	.0100	4.254	1465.8	98.81	1.97	1395.9
3000.00	0.00	1943	43395	1.913	1.1074	25.016	306	.0080	4.704	1526.9	254.05	2.08	1467.0
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	3400	59139	1.643	1.1494	37.808	424	0.0145					
1.74	8.46	3238	56948	1.680	1.1439	37.257	413	.0139	1.000	818.4	1.00	0.66	436.6
3.00	4.90	3090	54924	1.715	1.1392	35.357	403	.0132	1.438	862.8	1.16	0.91	605.6
10.00	1.47	2796	50911	1.791	1.1316	28.185	382	.0112	2.165	1005.7	2.40	1.28	846.2
30.00	0.49	2554	47709	1.856	1.1284	23.889	363	.0091	2.722	1116.6	5.39	1.50	997.3
100.00	0.15	2304	44633	1.922	1.1319	17.901	342	.0065	3.280	1215.8	13.91	1.69	1123.5
300.00	0.05	2068	42180	1.973	1.1516	11.654	321	.0041	3.760	1289.2	33.75	1.83	1214.8
1000.00	0.01	1744	39881	2.009	1.2608	5.609	288	.0019	4.242	1352.5	87.42	1.95	1294.5
3000.00	0.00	1354	38199	2.016	1.3505	3.808	245	.0012	4.820	1392.9	194.70	2.04	1349.9
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	3400	54026	1.779	1.1577	21.720	432	0.0099					
1.74	25.29	3218	51993	1.814	1.1537	20.529	419	.0091	1.000	785.1	1.00	0.66	420.6
3.00	14.70	3050	50147	1.848	1.1511	19.084	407	.0083	1.433	826.6	1.16	0.91	581.0
10.00	4.41	2702	46493	1.916	1.1517	14.971	379	.0061	2.161	960.2	2.37	1.27	809.6
30.00	1.47	2390	43631	1.969	1.1679	10.455	352	.0041	2.716	1061.4	5.21	1.50	951.1
100.00	0.44	2001	40982	2.007	1.2361	5.798	315	.0022	3.263	1146.3	12.73	1.68	1065.4
300.00	0.15	1573	39040	2.016	1.3316	3.985	270	.0014	3.809	1201.0	27.90	1.80	1141.9
1000.00	0.04	1149	37434	2.016	1.3701	3.649	220	.0010	4.625	1242.5	64.52	1.89	1201.5
3000.00	0.01	849	36360	2.016	1.3877	3.528	181	.0008	5.516	1265.2	138.63	1.95	1239.8
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	3400	50757	1.878	1.1727	14.110	438	0.0067					
1.75	83.75	3183	48816	1.909	1.1723	12.766	421	.0059	1.000	761.6	1.00	0.67	411.0
3.00	49.99	2983	47108	1.937	1.1750	11.298	405	.0050	1.425	799.7	1.15	0.92	564.4
10.00	14.70	2535	43744	1.987	1.2011	7.651	367	.0032	2.166	922.4	2.29	1.27	781.2
30.00	4.99	2088	41216	2.011	1.2687	4.945	324	.0020	2.700	1009.7	4.80	1.48	911.2
100.00	1.47	1576	39044	2.016	1.3385	3.807	270	.0013	3.356	1076.5	10.88	1.64	1009.6
300.00	0.49	1183	37558	2.016	1.3679	3.665	224	.0011	4.069	1119.0	23.08	1.74	1071.7
1000.00	0.15	850	36362	2.016	1.3877	3.528	181	.0008	4.978	1151.7	52.91	1.82	1119.2
3000.00	0.05	623	35570	2.016	1.3949	3.482	147	.0006	5.953	1172.8	113.40	1.87	1149.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	3400	49065	1.934	1.1911	10.078	440	0.0050					
1.77	249.15	3141	47160	1.959	1.1961	8.859	420	.0042	1.000	747.5	1.00	0.68	407.1
3.00	146.96	2905	45550	1.980	1.2063	7.655	400	.0035	1.414	782.5	1.14	0.92	553.0
10.00	44.09	2356	42394	2.009	1.2586	5.190	350	.0022	2.133	895.0	2.21	1.26	761.9
30.00	14.70	1846	40117	2.015	1.3187	4.109	299	.0016	2.730	972.1	4.47	1.46	882.4
100.00	4.41	1362	38224	2.016	1.3553	3.760	245	.0013	3.452	1031.4	9.98	1.61	971.3
300.00	1.47	1014	36945	2.016	1.3791	3.586	203	.0009	4.263	1069.3	21.08	1.70	1026.0
1000.00	0.44	724	35923	2.016	1.3931	3.493	163	.0007	5.149	1098.4	48.23	1.78	1069.4
3000.00	0.15	531	35249	2.016	1.3971	3.468	132	.0006	6.149	1117.2	103.38	1.82	1096.5
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	3400	48016	1.970	1.2137	7.561	442	0.0039					
1.79	822.19	3093	46124	1.989	1.2248	6.608	413	.0032	1.000	737.1	1.00	0.69	405.8
3.00	489.87	2822	44599	2.001	1.2411	5.783	393	.0027	1.402	768.9	1.19	0.92	545.3
10.00	146.96	2204	41609	2.014	1.2949	4.421	336	.0019	2.133	873.4	2.13	1.26	746.7
30.00	48.99	1695	39594	2.016	1.3336	3.945	283	.0014	2.764	945.1	4.27	1.45	860.6
100.00	14.70	1211	37773	2.016	1.3628	3.695	231	.0011	3.504	1000.4	9.52	1.59	944.1
300.00	4.90	923	36611	2.016	1.3842	3.551	190	.0009	4.263	1035.8	20.05	1.68	996.7
1000.00	1.47	656	35684	2.016	1.3944	3.485	153	.0007	5.230	1063.0	45.85	1.75	1035.9
3000.00	0.49	480	35074	2.016	1.3972	3.467	124	.0005	6.256	1080.6	98.31	1.79	1061.7

E-692

E-692

CT-4 back

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(n) Chamber temperature, 3600° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	3600	100473	1.026	1.2901	12.766	384	0.0058					
1.77	0.08	3298	96722	1.048	1.2001	23.870	365	.0095	1.000	1047.4	1.00	0.68	571.3
3.00	0.05	3107	93548	1.071	1.1656	35.455	354	.0133	1.436	1099.4	1.15	0.92	776.3
10.00	0.01	2801	87128	1.125	1.1311	61.313	336	.0213	2.184	1277.3	2.37	1.28	1077.6
30.00	0.00	2595	82013	1.175	1.1155	82.177	325	.0273	2.747	1418.0	5.37	1.51	1267.4
100.00	0.00	2410	77037	1.230	1.1042	101.318	314	.0324	3.301	1546.7	14.10	1.70	1428.0
300.00	0.00	2268	72967	1.279	1.0966	115.343	305	.0357	3.773	1646.2	35.34	1.84	1547.0
1000.00	0.00	2132	68936	1.332	1.0899	127.087	297	.0382	4.265	1740.1	99.29	1.97	1656.5
3000.00	0.00	2023	65593	1.380	1.0849	134.680	290	.0395	4.699	1814.9	259.33	2.07	1742.1
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	3600	97151	1.059	1.2078	24.275	388	0.0103					
1.75	0.25	3374	93523	1.085	1.1745	35.027	375	.0139	1.000	1040.3	1.00	0.67	561.9
3.00	0.15	3202	90332	1.111	1.1557	45.219	365	.0173	1.435	1093.8	1.15	0.92	770.3
10.00	0.04	2901	83940	1.169	1.1322	66.271	348	.0238	2.177	1272.2	2.38	1.28	1072.2
30.00	0.01	2687	78844	1.223	1.1176	82.512	336	.0284	2.739	1412.7	5.38	1.50	1262.9
100.00	0.00	2493	73895	1.280	1.1069	96.815	325	.0320	3.295	1540.9	14.10	1.70	1422.5
300.00	0.00	2342	69857	1.333	1.0993	106.739	315	.0342	3.771	1639.7	35.24	1.84	1541.1
1000.00	0.00	2198	65868	1.389	1.0926	114.359	306	.0355	4.268	1732.7	98.77	1.97	1649.9
3000.00	0.00	2081	62569	1.441	1.0875	118.519	299	.0359	4.707	1806.7	257.38	2.07	1734.7
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	3600	89099	1.147	1.1697	42.766	398	0.0178					
1.74	0.84	3418	85764	1.178	1.1563	50.384	388	.0203	1.000	1004.5	1.00	0.66	538.7
3.00	0.49	3262	82745	1.207	1.1461	57.244	379	.0225	1.437	1057.9	1.16	0.92	743.5
10.00	0.15	2973	76733	1.272	1.1293	70.237	363	.0262	2.171	1232.1	2.39	1.28	1037.3
30.00	0.05	2756	71929	1.330	1.1181	79.324	350	.0284	2.731	1368.8	5.41	1.50	1222.3
100.00	0.01	2554	67267	1.393	1.1086	86.318	338	.0297	3.288	1493.3	14.15	1.70	1378.3
300.00	0.00	2395	63469	1.450	1.1015	90.121	328	.0300	3.765	1589.0	35.30	1.84	1493.4
1000.00	0.00	2242	59725	1.512	1.0952	91.634	317	.0296	4.267	1678.9	98.70	1.97	1598.7
3000.00	0.00	2117	56635	1.567	1.0903	90.743	309	.0285	4.710	1750.2	256.60	2.07	1680.7
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	3600	78091	1.296	1.1577	49.837	413	0.0213					
1.74	2.53	3431	75144	1.329	1.1490	53.537	403	.0223	1.000	947.1	1.00	0.66	506.4
3.00	1.47	3281	72444	1.362	1.1416	56.640	395	.0230	1.438	998.1	1.16	0.91	701.0
10.00	0.44	2994	67079	1.433	1.1283	61.617	377	.0239	2.169	1163.3	2.40	1.28	978.9
30.00	0.15	2772	62787	1.498	1.1187	63.956	363	.0238	2.727	1292.7	5.42	1.50	1154.0
100.00	0.04	2563	58623	1.567	1.1103	64.223	349	.0229	3.284	1410.2	14.17	1.70	1301.5
300.00	0.01	2395	55237	1.628	1.1041	62.488	338	.0216	3.763	1500.4	35.28	1.84	1410.5
1000.00	0.00	2232	51907	1.695	1.0988	58.551	326	.0195	4.268	1584.8	98.35	1.97	1509.4
3000.00	0.00	2096	49168	1.754	1.0951	53.218	315	.0172	4.716	1651.5	254.80	2.07	1586.4
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	3600	66484	1.500	1.1552	40.271	430	0.0180					
1.74	8.45	3428	63939	1.536	1.1481	40.995	419	.0178	1.000	880.5	1.00	0.66	470.6
3.00	4.90	3274	61604	1.572	1.1420	41.295	409	.0175	1.437	927.9	1.16	0.91	651.7
10.00	1.47	2973	56968	1.649	1.1309	40.540	389	.0163	2.167	1081.2	2.40	1.28	910.0
30.00	0.49	2735	53258	1.717	1.1232	38.207	373	.0147	2.726	1200.8	5.40	1.50	1072.4
100.00	0.15	2505	49695	1.789	1.1175	33.954	355	.0125	3.286	1308.8	14.04	1.70	1208.7
300.00	0.05	2313	46807	1.852	1.1152	28.635	340	.0102	3.771	1391.0	34.71	1.84	1308.5
1000.00	0.01	2111	43998	1.916	1.1184	21.420	323	.0073	4.285	1466.9	95.51	1.96	1398.8
3000.00	0.00	1919	41730	1.967	1.1349	13.942	305	.0046	4.744	1525.1	241.77	2.06	1467.6
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	3600	58979	1.670	1.1590	27.871	442	0.0129					
1.74	25.30	3415	56689	1.708	1.1529	27.317	429	.0123	1.000	833.7	1.00	0.66	446.5
3.00	14.70	3247	54605	1.743	1.1480	26.441	418	.0116	1.435	878.0	1.16	0.91	617.0
10.00	4.41	2913	50472	1.819	1.1403	23.381	393	.0097	2.164	1021.3	2.38	1.28	860.4
30.00	1.47	2638	47201	1.884	1.1384	19.331	372	.0076	2.727	1132.0	5.31	1.50	1012.4
100.00	0.44	2349	44086	1.947	1.1471	13.776	347	.0052	3.291	1230.0	13.57	1.69	1138.4
300.00	0.15	2063	41638	1.992	1.1835	8.337	321	.0030	3.773	1301.3	32.40	1.82	1228.4
1000.00	0.04	1658	39406	2.014	1.3011	4.380	279	.0015	4.289	1359.6	80.81	1.93	1305.0
3000.00	0.01	1257	37832	2.016	1.3619	3.711	233	.0011	5.006	1396.2	176.69	2.01	1356.4
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	3600	53950	1.808	1.1692	17.918	450	0.0086					
1.75	83.97	3387	51822	1.843	1.1652	16.846	435	.0079	1.000	799.6	1.00	0.67	430.3
3.00	48.99	3194	49927	1.875	1.1631	15.556	420	.0070	1.430	840.6	1.15	0.92	591.7
10.00	14.70	2789	46177	1.940	1.1672	11.902	388	.0051	2.159	973.6	2.33	1.27	822.4
30.00	4.90	2420	43279	1.986	1.1935	8.056	356	.0033	2.718	1072.9	5.07	1.49	963.6
100.00	1.47	1958	40654	2.012	1.2769	4.778	311	.0018	3.282	1153.8	12.10	1.66	1075.6
300.00	0.49	1508	38779	2.016	1.3430	3.867	262	.0013	3.899	1205.2	26.12	1.78	1148.9
1000.00	0.15	1097	37244	2.016	1.3737	3.623	213	.0010	4.744	1244.7	60.35	1.87	1205.7
3000.00	0.05	809	36220	2.016	1.3895	3.516	175	.0008	5.657	1270.0	129.68	1.92	1242.1
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	3600	51303	1.890	1.1837	12.371	455	0.0062					
1.76	250.30	3351	49251	1.920	1.1833	11.234	436	.0054	1.000	779.6	1.00	0.67	422.5
3.00	146.96	3125	47479	1.946	1.1865	9.995	418	.0047	1.421	817.5	1.14	0.92	576.8
10.00	44.09	2623	43987	1.992	1.2144	6.925	375	.0030	2.146	940.6	2.26	1.27	797.9
30.00	14.70	2137	41390	2.012	1.2778	4.750	329	.0019	2.711	1027.6	4.71	1.48	928.7
100.00	4.41	1609	39171	2.016	1.3273	3.915	274	.0014	3.382	1094.6	10.68	1.63	1027.4
300.00	1.47	1209	37654	2.016	1.3661	3.678	227	.0011	4.095	1137.4	22.68	1.73	1089.8
1000.00	0.44	869	36431	2.016	1.3868	3.534	183	.0008	5.004	1170.3	52.08	1.81	1137.6
3000.00	0.15	638	35621	2.016	1.3947	3.483	150	.0007	5.981	1191.6	111.69	1.86	1168.1
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	3600	49653	1.945	1.2036	8.853	458	0.0046					
1.78	826.84	3302	47638	1.968	1.2089	7.869	434	.0039	1.000	765.2	1.00	0.68	418.8
3.00	489.87	3039	45970	1.986	1.2191	6.912	412	.0033	1.410	799.9	1.13	0.92	566.1
10.00	146.96	2436	42694	2.010	1.2671	4.974	358	.0022	2.136	912.9	2.18	1.26	778.2
30.00	48.99	1904	40345	2.016	1.3177	4.113	305	.0016	2.744	990.7	4.42	1.46	900.0
100.00	14.70	1407	38392	2.016	1.3526	3.783	251	.0012	3.466	1050.8	9.89	1.61	989.9
300.00	4.90	1048	37070	2.016	1.3769	3.601	207	.0010	4.206	1089.3	20.93	1.70	1046.4
1000.00	1.47	750	36012	2.016	1.3921	3.500	167	.0007	5.149	1119.0	47.96	1.77	1089.5
3000.00	0.49	550	35314	2.016	1.3965	3.472	135	.0006	6.157	1138.1	102.80	1.81	1117.0

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(o) Chamber temperature, 3800° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	3800	102507	1.016	1.4034	8.248	396	0.0042					
1.79	0.08	3383	98496	1.035	1.2349	17.607	369	.0073	1.000	1069.1	1.00	0.69	590.7
3.00	0.05	3161	95274	1.056	1.1809	28.765	356	.0110	1.435	1119.6	1.14	0.93	793.9
10.00	0.01	2828	88679	1.109	1.1355	55.683	337	.0195	2.192	1297.9	2.35	1.28	1096.9
30.00	0.00	2613	83447	1.158	1.1176	77.962	324	.0259	2.759	1439.2	5.31	1.51	1287.8
100.00	0.00	2424	78359	1.212	1.1054	98.693	314	.0315	3.315	1568.5	13.96	1.70	1449.2
300.00	0.00	2279	74220	1.261	1.0974	114.107	305	.0353	3.789	1668.5	34.98	1.84	1568.9
1000.00	0.00	2142	70114	1.314	1.0904	127.279	296	.0382	4.283	1762.8	98.29	1.97	1678.9
3000.00	0.00	2031	66710	1.362	1.0853	136.079	289	.0399	4.717	1838.0	256.71	2.07	1764.9
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	3800	100859	1.032	1.2796	14.001	398	0.0065					
1.77	0.25	3487	96909	1.056	1.2037	24.479	375	.0101	1.000	1073.4	1.00	0.68	586.2
3.00	0.15	3283	93588	1.080	1.1717	35.066	368	.0137	1.433	1125.9	1.15	0.92	785.4
10.00	0.04	2948	86879	1.137	1.1373	58.520	349	.0211	2.184	1306.3	2.35	1.28	1102.9
30.00	0.01	2721	81561	1.189	1.1209	77.275	336	.0266	2.751	1448.6	5.31	1.50	1295.8
100.00	0.00	2520	76414	1.245	1.1089	94.286	324	.0312	3.312	1578.4	13.91	1.69	1458.5
300.00	0.00	2364	72222	1.297	1.1007	106.543	315	.0341	3.790	1678.4	34.74	1.83	1578.6
1000.00	0.00	2217	68256	1.353	1.0936	116.536	306	.0361	4.290	1772.6	97.32	1.96	1688.7
3000.00	0.00	2098	64658	1.403	1.0882	122.694	298	.0370	4.731	1847.4	253.56	2.06	1774.6
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	3800	96095	1.080	1.2032	27.679	404	0.0120					
1.76	0.84	3566	92332	1.108	1.1768	37.085	391	.0153	1.000	1058.4	1.00	0.67	572.2
3.00	0.49	3394	89037	1.136	1.1603	45.916	381	.0182	1.433	1112.3	1.15	0.92	783.6
10.00	0.15	3058	82445	1.198	1.1367	63.529	363	.0238	2.176	1292.3	2.37	1.28	1089.8
30.00	0.05	2823	77214	1.254	1.1229	76.869	350	.0275	2.742	1433.5	5.33	1.50	1281.7
100.00	0.01	2610	72150	1.316	1.1117	88.252	337	.0303	3.305	1562.0	13.92	1.69	1443.1
300.00	0.00	2444	68054	1.371	1.1037	95.762	327	.0318	3.787	1660.7	34.68	1.83	1562.0
1000.00	0.00	2286	64016	1.431	1.0966	101.003	317	.0325	4.292	1753.6	96.97	1.96	1670.7
3000.00	0.00	2159	60687	1.484	1.0912	103.221	308	.0323	4.738	1826.9	251.74	2.06	1755.2
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	3800	87412	1.180	1.1754	42.088	416	0.0183					
1.75	2.52	3601	83981	1.212	1.1622	48.360	405	.0204	1.000	1016.6	1.00	0.67	546.4
3.00	1.47	3432	80996	1.243	1.1521	53.889	396	.0221	1.435	1069.7	1.15	0.92	752.4
10.00	0.44	3115	74781	1.311	1.1349	64.147	377	.0249	2.172	1244.3	2.38	1.28	1048.4
30.00	0.15	2877	69911	1.373	1.1237	70.979	365	.0264	2.735	1380.8	5.36	1.50	1234.0
100.00	0.05	2656	65207	1.440	1.1132	75.766	350	.0270	3.298	1504.8	13.96	1.69	1390.0
300.00	0.01	2483	61391	1.499	1.1059	77.785	338	.0268	3.782	1599.0	34.73	1.83	1504.7
1000.00	0.00	2316	57645	1.564	1.0993	77.579	327	.0258	4.290	1688.9	96.80	1.96	1609.4
3000.00	0.00	2180	54555	1.622	1.0942	75.318	317	.0243	4.741	1759.3	250.96	2.06	1690.6
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	3800	74985	1.360	1.1650	43.825	434	0.0198					
1.74	8.43	3611	72016	1.396	1.1560	46.299	423	.0203	1.000	948.2	1.00	0.66	508.4
3.00	4.90	3445	69325	1.431	1.1484	48.242	413	.0206	1.435	998.4	1.16	0.91	701.8
10.00	1.47	3125	63978	1.506	1.1345	50.905	393	.0206	2.169	1162.0	2.38	1.28	978.7
30.00	0.49	2879	59724	1.574	1.1244	51.404	377	.0199	2.732	1289.5	5.36	1.50	1152.3
100.00	0.15	2647	55621	1.646	1.1161	49.929	361	.0185	3.296	1405.1	13.96	1.69	1298.1
300.00	0.05	2460	52301	1.711	1.1101	46.839	348	.0167	3.782	1493.4	34.61	1.83	1404.9
1000.00	0.01	2276	49055	1.779	1.1055	41.659	334	.0143	4.296	1575.7	95.99	1.96	1502.1
3000.00	0.00	2121	46402	1.835	1.1035	34.413	321	.0118	4.754	1640.3	247.95	2.06	1577.1
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	3800	65156	1.548	1.1642	33.725	449	0.0158					
1.74	25.27	3605	62544	1.585	1.1566	34.100	437	.0155	1.000	889.1	1.00	0.66	476.8
3.00	14.70	3431	60181	1.622	1.1500	34.091	425	.0151	1.435	936.0	1.16	0.91	658.0
10.00	4.41	3092	55488	1.701	1.1385	32.778	402	.0137	2.168	1088.6	2.38	1.28	917.2
30.00	1.47	2825	51768	1.770	1.1310	30.083	383	.0120	2.732	1207.2	5.33	1.50	1079.4
100.00	0.46	2564	48200	1.842	1.1265	25.592	362	.0097	3.299	1313.7	13.77	1.69	1214.7
300.00	0.15	2341	45341	1.903	1.1277	20.236	345	.0074	3.791	1394.1	33.78	1.83	1313.1
1000.00	0.04	2095	42593	1.962	1.1625	13.362	323	.0047	4.314	1467.1	91.61	1.95	1401.3
3000.00	0.01	1830	40426	2.002	1.1990	7.146	297	.0024	4.763	1520.8	224.77	2.04	1466.9
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	3800	57958	1.721	1.1698	22.212	461	0.0109					
1.75	84.03	3584	55601	1.758	1.1636	21.572	446	.0102	1.000	842.0	1.00	0.67	452.8
3.00	48.99	3392	53495	1.793	1.1588	20.657	432	.0095	1.431	885.5	1.15	0.92	623.1
10.00	14.70	3005	49319	1.867	1.1527	17.618	404	.0076	2.165	1027.5	2.35	1.27	867.0
30.00	4.90	2681	46050	1.928	1.1556	13.788	378	.0056	2.731	1136.0	5.20	1.50	1017.9
100.00	1.47	2323	42986	1.982	1.1810	8.916	346	.0035	3.299	1230.2	13.04	1.68	1141.4
300.00	0.49	1942	40648	2.010	1.2579	5.191	309	.0019	3.786	1295.3	30.00	1.80	1227.3
1000.00	0.15	1467	38624	2.016	1.3449	3.851	258	.0013	4.459	1345.5	71.26	1.91	1297.0
3000.00	0.05	1096	37244	2.016	1.3737	3.623	215	.0010	5.282	1377.5	154.36	1.97	1342.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	3800	54041	1.833	1.1804	15.070	468	0.0076					
1.76	250.53	3554	51815	1.867	1.1765	14.129	450	.0069	1.000	814.1	1.00	0.67	440.1
3.00	146.96	3335	49870	1.897	1.1750	13.006	433	.0062	1.426	854.6	1.15	0.92	602.4
10.00	44.09	2870	46022	1.957	1.1828	9.822	396	.0043	2.157	987.1	2.30	1.27	835.3
30.00	14.70	2443	43088	1.997	1.2178	6.653	358	.0028	2.720	1084.6	4.94	1.49	976.3
100.00	4.41	1928	40478	2.014	1.2992	4.384	308	.0017	3.313	1162.5	11.59	1.65	1086.3
300.00	1.47	1472	38643	2.016	1.3471	3.828	258	.0013	3.969	1212.1	24.90	1.76	1157.5
1000.00	0.44	1069	37145	2.016	1.3755	3.610	210	.0010	4.828	1250.3	57.53	1.85	1212.5
3000.00	0.15	785	36146	2.016	1.3905	3.510	172	.0008	5.756	1274.9	123.66	1.90	1247.8
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	3800	51574	1.911	1.1970	10.391	472	0.0055					
1.77	830.23	3599	49420	1.939	1.1974	9.457	450	.0048	1.000	794.4	1.00	0.68	432.9
3.00	489.87	3352	47603	1.961	1.2019	8.453	429	.0041	1.416	831.7	1.14	0.92	587.8
10.00	146.96	2680	44022	1.999	1.2340	6.234	380	.0027	2.144	953.6	2.23	1.27	810.6
30.00	48.99	2149	41396	2.014	1.2919	4.491	330	.0018	2.726	1039.1	4.59	1.47	941.1
100.00	14.70	1610	39173	2.016	1.3385	3.901	274	.0014	3.417	1105.2	10.38	1.62	1038.8
300.00	4.90	1209	37655	2.016	1.3661	3.678	227	.0011	4.135	1147.6	22.08	1.72	1100.5
1000.00	1.47	869	36432	2.016	1.3858	3.534	184	.0008	5.049	1180.3	50.74	1.79	1147.9
3000.00	0.49	638	35622	2.016	1.3947	3.483	150	.0007	6.031	1201.4	108.87	1.84	1178.9

E-692

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(p) Chamber temperature, 4000° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, κ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	4000	103946	1.012	1.5075	6.409	409	0.0036					
1.80	0.08	3457	99687	1.027	1.4729	13.760	374	.0060	1.000	1086.9	1.00	0.71	608.7
3.00	0.05	3206	96450	1.046	1.1961	24.192	358	.0095	1.435	1135.6	1.14	0.94	807.6
10.00	0.01	2848	89727	1.099	1.1391	51.815	337	.0181	2.202	1313.8	2.33	1.29	1112.3
30.00	0.00	2625	84415	1.147	1.1193	74.822	325	.0249	2.771	1455.4	5.27	1.51	1303.6
100.00	0.00	2433	79266	1.201	1.1063	95.630	313	.0309	3.329	1585.0	13.55	1.70	1465.4
300.00	0.00	2286	75063	1.249	1.0980	112.997	303	.0350	3.803	1685.1	34.69	1.84	1585.3
1000.00	0.00	2148	70904	1.302	1.0908	127.149	296	.0382	4.298	1779.7	97.48	1.96	1695.5
3000.00	0.00	2037	67461	1.349	1.0855	136.781	289	.0400	4.734	1855.0	254.60	2.05	1781.8
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	4000	103113	1.020	1.3756	9.169	410	0.0047					
1.79	0.25	3579	98890	1.040	1.3357	18.340	384	.0079	1.000	1096.7	1.00	0.69	606.2
3.00	0.15	3344	95507	1.063	1.2868	28.656	370	.0114	1.432	1147.9	1.14	0.93	813.6
10.00	0.04	2979	88595	1.118	1.1419	52.248	349	.0193	2.1921	1228.9	2.33	1.28	1124.0
30.00	0.01	2742	83143	1.170	1.1232	72.448	336	.0253	2.7653	1472.0	5.26	1.50	1318.7
100.00	0.00	2535	77877	1.226	1.1102	92.064	324	.0304	3.326	1603.5	13.76	1.69	1481.8
300.00	0.00	2377	73595	1.277	1.1016	105.924	314	.0338	3.806	1703.1	34.37	1.83	1602.7
1000.00	0.00	2228	69373	1.332	1.0942	117.153	305	.0363	4.308	1797.8	96.27	1.95	1713.4
3000.00	0.00	2133	65897	1.382	1.0886	124.531	298	.0376	4.750	1873.1	250.80	2.05	1799.8
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	4000	100474	1.045	1.3566	17.077	413	0.0080					
1.77	0.83	3691	96359	1.072	1.3022	26.863	386	.0115	1.000	1096.1	1.00	0.68	598.4
3.00	0.49	3478	92896	1.093	1.1755	36.293	384	.0147	1.431	1149.5	1.14	0.92	812.0
10.00	0.15	3115	85918	1.158	1.1432	56.704	363	.0213	2.182	1332.2	2.34	1.28	1125.4
30.00	0.05	2866	80415	1.213	1.1266	72.720	349	.0261	2.754	1475.8	5.26	1.50	1321.1
100.00	0.01	2644	75116	1.273	1.1160	86.947	337	.0299	3.321	1606.3	13.72	1.69	1485.4
300.00	0.00	2473	70829	1.327	1.1059	96.890	326	.0322	3.806	1706.6	34.15	1.82	1606.3
1000.00	0.00	2311	66603	1.385	1.0977	104.596	316	.0336	4.314	1800.8	95.36	1.95	1716.7
3000.00	0.00	2182	63130	1.438	1.0920	108.880	308	.0340	4.763	1875.4	247.74	2.05	1802.6
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	4000	94654	1.106	1.2021	30.256	421	0.0136					
1.76	2.51	3766	90770	1.136	1.1890	38.385	408	.0165	1.000	1072.7	1.00	0.67	580.7
3.00	1.47	3562	87406	1.162	1.1652	45.722	397	.0190	1.432	1122.8	1.15	0.92	794.5
10.00	0.44	3209	80660	1.232	1.1620	60.335	378	.0225	2.176	1307.6	2.36	1.28	1103.5
30.00	0.15	2951	75533	1.291	1.1279	71.029	363	.0264	2.746	1449.1	5.28	1.50	1296.6
100.00	0.04	2721	70208	1.356	1.1163	79.758	349	.0284	3.314	1577.4	13.75	1.69	1458.5
300.00	0.01	2540	66063	1.414	1.1059	85.098	338	.0293	3.802	1675.8	34.15	1.82	1577.3
1000.00	0.00	2368	62002	1.477	1.1005	88.216	327	.0293	4.315	1767.8	95.09	1.95	1685.6
3000.00	0.00	2230	58658	1.533	1.0940	88.716	317	.0286	4.769	1840.6	246.44	2.05	1769.6
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	4000	83597	1.243	1.1791	41.255	437	0.0188					
1.75	8.39	3785	79152	1.278	1.1675	45.735	426	.0202	1.000	1015.2	1.00	0.67	546.7
3.00	4.90	3602	75108	1.311	1.1573	49.552	415	.0213	1.433	1067.6	1.15	0.92	751.4
10.00	1.47	3256	71027	1.384	1.1402	56.247	394	.0228	2.172	1240.3	2.37	1.28	1045.8
30.00	0.49	2995	66216	1.450	1.1284	60.144	379	.0234	2.739	1375.0	5.31	1.50	1229.8
100.00	0.15	2753	61589	1.521	1.1181	62.065	363	.0231	3.308	1496.9	13.79	1.69	1383.9
300.00	0.05	2562	57853	1.584	1.1106	61.777	350	.0221	3.798	1590.1	34.18	1.82	1496.7
1000.00	0.01	2378	54202	1.652	1.1041	59.353	337	.0205	4.314	1677.1	94.89	1.95	1599.3
3000.00	0.00	2228	51216	1.713	1.0994	55.133	326	.0185	4.774	1745.6	245.09	2.05	1678.6
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	4000	72340	1.423	1.1727	37.535	454	0.0178					
1.76	25.21	3789	69343	1.461	1.1633	39.251	441	.0180	1.000	949.7	1.00	0.67	510.7
3.00	14.70	3604	66662	1.491	1.1554	40.403	430	.0180	1.433	999.1	1.15	0.92	702.9
10.00	4.41	3249	61331	1.576	1.1410	41.510	408	.0175	2.170	1160.9	2.37	1.28	978.7
30.00	1.47	2976	57114	1.646	1.1309	40.903	389	.0170	2.737	1286.3	5.30	1.50	1151.0
100.00	0.44	2718	53071	1.720	1.1224	38.226	371	.0147	3.307	1400.3	13.74	1.69	1294.9
300.00	0.15	2506	49818	1.780	1.1174	34.322	356	.0127	3.800	1486.6	33.89	1.82	1399.9
1000.00	0.04	2299	46660	1.855	1.1149	28.468	339	.0101	4.325	1566.5	93.39	1.95	1494.8
3000.00	0.01	2116	44192	1.913	1.1178	21.857	323	.0074	4.795	1628.5	238.40	2.04	1567.5
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	4000	62840	1.622	1.1738	26.571	470	0.0132					
1.76	83.97	3776	60205	1.660	1.1659	26.533	452	.0133	1.000	889.5	1.00	0.67	478.8
3.00	48.99	3579	57800	1.693	1.1592	26.174	442	.0132	1.432	935.3	1.15	0.92	658.3
10.00	14.70	3191	53230	1.776	1.1482	24.229	415	.0106	2.169	1085.5	2.36	1.27	915.9
30.00	4.90	2883	49538	1.844	1.1426	21.149	392	.0088	2.737	1201.5	5.24	1.50	1075.8
100.00	1.47	2574	46063	1.912	1.1434	16.493	367	.0065	3.312	1306.6	13.40	1.68	1208.7
300.00	0.49	2294	43321	1.966	1.1587	11.404	343	.0043	3.801	1380.7	32.32	1.81	1303.2
1000.00	0.15	1949	40763	2.055	1.2263	6.108	309	.0022	4.328	1446.3	83.94	1.93	1386.0
3000.00	0.05	1531	38876	2.016	1.3326	3.979	265	.0013	4.882	1489.5	189.76	2.01	1444.0
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	4000	57352	1.763	1.1806	18.086	479	0.0093					
1.76	251.14	3751	54921	1.800	1.1743	17.440	462	.0086	1.000	851.7	1.00	0.67	460.0
3.00	146.96	3533	52787	1.834	1.1698	16.565	446	.0080	1.428	894.6	1.15	0.92	630.3
10.00	44.09	3087	48564	1.904	1.1662	13.718	412	.0062	2.164	1035.2	2.33	1.27	875.0
30.00	14.70	2708	45280	1.959	1.1750	10.279	381	.0044	2.734	1141.6	5.08	1.49	1024.9
100.00	4.41	2274	42256	2.001	1.2224	6.374	342	.0026	3.306	1231.5	13.47	1.67	1145.7
300.00	1.47	1821	40037	2.015	1.3067	4.281	293	.0016	3.841	1291.1	27.77	1.79	1227.5
1000.00	0.44	1347	38166	2.016	1.3560	3.755	244	.0012	4.617	1336.8	64.99	1.88	1292.1
3000.00	0.15	1002	36902	2.016	1.3799	3.580	201	.0009	5.479	1366.1	140.48	1.94	1333.9
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	4000	53826	1.868	1.1935	12.164	485	0.0065					
1.77	832.33	3711	51514	1.900	1.1905	11.344	464	.0058	1.000	825.1	1.00	0.67	448.4
3.00	489.87	3459	49541	1.927	1.1904	10.393	445	.0052	1.421	864.8	1.14	0.92	610.6
10.00	146.96	2917	45639	1.978	1.2050	7.757	401	.0036	2.154	995.1	2.37	1.27	844.0
30.00	48.99	2419	47716	2.006	1.3507	5.429	356	.0025	2.724	1089.2	4.78	1.48	983.2
100.00	14.70	1860	40173	2.015	1.3173	4.126	301	.0016	3.362	1163.1	11.00	1.64	1089.9
300.00	4.90	1411	38410	2.016	1.3519	4.787	251	.0012	2.046	1210.4	23.57	1.74	1158.7
1000.00	1.47	1022	36976	2.016	1.3784	3.589	204	.0009	4.935	1247.0	54.63	1.82	1210.8
3000.00	0.49	753	36022	2.016	1.3920	3.501	167	.0007	5.871	1270.6	116.99	1.87	1244.6

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(q) Chamber temperature, 4200° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	4200	105139	1.010	1.5785	5.630	421	0.0034					
1.83	0.08	3531	100618	1.022	1.3163	11.111	378	.0051	1.000	1103.7	1.00	0.72	627.2
3.00	0.05	3248	97389	1.039	1.2128	20.609	360	.0082	1.434	1150.2	1.13	0.94	821.2
10.00	0.01	2864	90559	1.090	1.1425	48.249	338	.0170	2.211	1328.0	2.31	1.29	1126.3
30.00	0.00	2636	85181	1.139	1.1207	72.168	325	.0241	2.783	1469.6	5.22	1.51	1317.8
100.00	0.00	2440	79976	1.192	1.1071	94.830	313	.0303	3.343	1599.3	13.73	1.70	1479.7
300.00	0.00	2292	75730	1.240	1.0984	111.958	304	.0347	3.818	1699.6	34.40	1.84	1599.7
1000.00	0.00	2153	71532	1.293	1.0912	126.896	296	.0381	4.314	1794.2	96.68	1.96	1710.0
3000.00	0.00	2041	68055	1.340	1.0858	137.196	289	.0401	4.750	1869.7	252.54	2.06	1796.3
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	4200	104700	1.014	1.4724	6.982	422	0.0039					
1.50	0.24	3659	100222	1.031	1.2702	14.490	388	.0065	1.000	1115.6	1.00	0.70	624.2
3.00	0.15	3393	96812	1.052	1.2017	24.240	372	.0099	1.431	1165.1	1.13	0.93	828.5
10.00	0.04	3022	89754	1.107	1.1457	49.400	350	.0180	2.200	1346.1	2.31	1.29	1140.4
30.00	0.01	2757	84208	1.158	1.1250	70.545	336	.0244	2.774	1489.5	5.21	1.51	1335.3
100.00	0.00	2546	78862	1.213	1.1112	90.255	324	.0298	3.339	1620.4	13.64	1.69	1499.4
300.00	0.00	2386	74517	1.264	1.1022	104.876	314	.0335	3.821	1721.3	34.07	1.83	1620.6
1000.00	0.00	2235	70238	1.319	1.0946	117.292	305	.0363	4.324	1816.3	95.42	1.95	1731.7
3000.00	0.00	2115	66705	1.368	1.0890	125.496	297	.0378	4.767	1891.8	248.61	2.05	1818.3
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	4200	103742	1.028	1.3310	11.236	424	0.0057					
1.79	0.82	3795	98829	1.052	1.2307	20.309	400	.0090	1.000	1123.2	1.00	0.69	619.7
3.00	0.49	3550	95273	1.076	1.1904	29.737	386	.0123	1.429	1175.4	1.14	0.93	832.7
10.00	0.15	3154	88038	1.135	1.1484	51.557	364	.0195	2.189	1359.2	2.32	1.28	1150.2
30.00	0.05	2893	82363	1.189	1.1293	69.196	349	.0249	2.765	1504.0	5.20	1.50	1347.9
100.00	0.01	2664	76912	1.248	1.1156	85.204	336	.0293	3.336	1635.6	13.56	1.68	1513.6
300.00	0.00	2490	72500	1.302	1.1064	96.691	326	.0321	3.823	1736.7	33.75	1.82	1635.5
1000.00	0.00	2326	68172	1.360	1.0985	105.970	316	.0340	4.333	1831.6	94.19	1.94	1746.9
3000.00	0.00	2195	64611	1.412	1.0925	111.575	307	.0348	4.784	1906.7	244.68	2.04	1833.4
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	4200	99648	1.063	1.2426	20.247	429	0.0096					
1.77	2.49	3891	95393	1.092	1.2019	29.126	412	.0129	1.000	1114.8	1.00	0.68	608.5
3.00	1.47	3668	91814	1.120	1.1792	37.388	400	.0158	1.429	1168.7	1.14	0.92	825.6
10.00	0.44	3277	84616	1.183	1.1487	54.870	378	.0215	2.181	1353.0	2.33	1.28	1143.7
30.00	0.15	3005	78967	1.242	1.1319	68.267	363	.0255	2.757	1497.4	5.22	1.50	1341.5
100.00	0.04	2762	73553	1.305	1.1188	79.889	349	.0285	3.330	1628.3	13.55	1.68	1506.9
300.00	0.01	2576	69184	1.362	1.1097	87.665	337	.0302	3.822	1728.6	33.62	1.82	1628.1
1000.00	0.00	2400	64911	1.423	1.1017	93.241	326	.0310	4.338	1822.4	93.56	1.94	1738.5
3000.00	0.00	2260	61407	1.479	1.0957	95.791	317	.0309	4.795	1896.5	242.39	2.04	1824.1
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	4200	91158	1.158	1.1990	33.844	441	0.0158					
1.76	8.35	3949	87266	1.191	1.1814	40.132	427	.0180	1.000	1074.5	1.00	0.67	581.9
3.00	4.90	3744	83887	1.222	1.1684	45.640	416	.0198	1.430	1128.3	1.15	0.92	795.4
10.00	1.47	3364	77137	1.293	1.1469	56.212	395	.0229	2.175	1308.2	2.35	1.27	1104.5
30.00	0.49	3085	71829	1.357	1.1328	63.464	379	.0247	2.748	1448.5	5.24	1.50	1296.9
100.00	0.15	2832	66745	1.426	1.1210	68.785	363	.0256	3.322	1575.3	13.59	1.68	1457.5
300.00	0.05	2634	62651	1.488	1.1125	71.333	351	.0256	3.816	1672.2	33.65	1.82	1575.0
1000.00	0.01	2446	58657	1.554	1.1049	71.732	338	.0248	4.337	1762.6	93.38	1.94	1681.7
3000.00	0.00	2295	55392	1.614	1.0992	70.038	328	.0234	4.799	1833.8	241.23	2.04	1764.1
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	4200	79971	1.311	1.1845	37.999	458	0.0182					
1.73	25.13	3966	76542	1.348	1.1727	41.105	445	.0190	1.000	1012.0	1.00	0.67	546.2
3.00	14.70	3767	73523	1.383	1.1630	43.633	433	.0196	1.431	1063.5	1.15	0.92	749.0
10.00	4.41	3387	67509	1.460	1.1458	47.696	411	.0202	2.172	1233.9	2.35	1.27	1041.3
30.00	1.47	3101	62774	1.529	1.1337	49.462	393	.0200	2.744	1366.6	5.26	1.50	1223.2
100.00	0.44	2836	58243	1.603	1.1234	49.341	375	.0190	3.318	1486.2	13.61	1.68	1375.0
300.00	0.15	2626	54602	1.670	1.1160	47.439	360	.0176	3.814	1577.3	33.60	1.82	1485.7
1000.00	0.04	2422	51061	1.740	1.1099	43.505	346	.0155	4.339	1661.9	92.88	1.94	1586.0
3000.00	0.01	2254	48180	1.802	1.1063	38.332	332	.0132	4.808	1728.2	238.75	2.04	1663.2
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	4200	68543	1.516	1.1805	30.283	476	0.0152					
1.75	83.82	3962	65579	1.555	1.1710	31.041	462	.0150	1.000	961.6	1.00	0.67	507.9
3.00	48.99	3756	62962	1.592	1.1630	31.414	449	.0148	1.431	989.6	1.15	0.92	696.9
10.00	14.70	3357	57757	1.673	1.1487	30.999	423	.0137	2.170	1147.9	2.35	1.27	968.8
30.00	4.90	3049	53668	1.744	1.1393	29.134	401	.0122	2.742	1270.5	5.24	1.50	1137.9
100.00	1.47	2753	49775	1.819	1.1327	25.547	379	.0102	3.319	1380.3	13.46	1.68	1277.9
300.00	0.49	2508	46673	1.883	1.1314	20.983	360	.0080	3.822	1463.0	32.93	1.81	1379.5
1000.00	0.15	2247	43701	1.945	1.1400	14.823	338	.0054	4.357	1538.2	89.32	1.93	1470.2
3000.00	0.05	1986	41350	1.991	1.1756	8.806	313	.0031	4.830	1594.3	221.21	2.02	1538.2
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	4200	61284	1.683	1.1836	21.225	489	0.0111					
1.76	251.05	3943	58608	1.722	1.1755	20.985	472	.0105	1.000	892.9	1.00	0.67	482.5
3.00	146.96	3721	56265	1.757	1.1691	20.472	457	.0100	1.429	937.8	1.15	0.92	660.8
10.00	44.09	3279	51608	1.834	1.1592	18.312	425	.0083	2.168	1086.0	2.33	1.27	917.5
30.00	14.70	2923	47984	1.899	1.1569	15.210	398	.0065	2.741	1199.5	5.15	1.49	1075.8
100.00	4.41	2553	44589	1.960	1.1684	10.854	367	.0044	3.322	1298.7	12.96	1.67	1205.3
300.00	1.47	2192	41969	1.999	1.2129	6.753	334	.0026	3.823	1369.5	30.43	1.80	1296.4
1000.00	0.44	1721	39632	2.015	1.3139	4.190	286	.0015	4.407	1426.4	74.62	1.90	1372.6
3000.00	0.15	1303	38001	2.016	1.3590	3.732	238	.0011	5.166	1462.6	163.34	1.97	1423.3
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	4200	56452	1.816	1.1928	14.125	498	0.0077					
1.76	833.34	3909	53960	1.851	1.1873	13.488	477	.0070	1.000	857.8	1.00	0.67	465.6
3.00	489.87	3657	51821	1.882	1.1839	12.673	459	.0064	1.423	899.5	1.14	0.92	634.8
10.00	146.96	3135	47578	1.944	1.1858	10.119	419	.0047	2.161	1037.4	2.29	1.27	878.7
30.00	48.99	2680	44350	1.987	1.2086	7.299	380	.0032	2.734	1139.8	4.92	1.48	1026.2
100.00	14.70	2152	41458	2.012	1.2752	4.803	331	.0020	3.326	1223.2	11.70	1.65	1142.2
300.00	4.90	1666	39393	2.016	1.3329	3.960	280	.0014	3.948	1277.0	25.43	1.76	1218.3
1000.00	1.47	1219	37692	2.016	1.3653	3.684	228	.0011	4.782	1318.6	59.17	1.85	1277.6
3000.00	0.49	903	36551	2.016	1.3851	3.545	188	.0009	5.682	1345.4	127.64	1.90	1315.9

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(r) Chamber temperature, 4400° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	4400	106226	1.009	1.6192	5.280	434	0.0033					
1.86	0.08	3608	101414	1.018	1.3656	9.200	383	.0044	1.000	1120.8	1.00	0.74	647.0
3.00	0.05	3291	98216	1.033	1.2324	17.574	363	.0072	1.433	1164.7	1.12	0.95	834.8
10.00	0.01	2880	91285	1.083	1.1458	45.220	338	.0160	2.222	1341.7	2.29	1.30	1140.2
30.00	0.00	2645	85848	1.132	1.1221	69.738	325	.0233	2.796	1483.3	5.17	1.51	1331.6
100.00	0.00	2447	80593	1.184	1.1078	93.142	313	.0298	3.357	1613.0	13.60	1.70	1493.4
300.00	0.00	2298	76310	1.232	1.0989	110.937	304	.0343	3.834	1713.3	34.08	1.83	1613.4
1000.00	0.00	2157	72077	1.285	1.0914	126.568	296	.0380	4.330	1808.0	95.78	1.96	1723.8
3000.00	0.00	2045	68571	1.332	1.0860	137.457	289	.0402	4.767	1883.4	250.24	2.06	1810.1
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	4400	105983	1.011	1.5478	5.970	434	0.0036					
1.82	0.24	3735	101246	1.025	1.3083	11.832	393	.0056	1.000	1132.7	1.00	0.72	642.0
3.00	0.15	3438	97821	1.044	1.2174	20.835	375	.0086	1.431	1180.3	1.13	0.94	842.7
10.00	0.04	3021	90653	1.098	1.1492	46.269	350	.0170	2.209	1361.0	2.30	1.29	1135.0
30.00	0.01	2769	85033	1.148	1.1265	68.125	336	.0236	2.786	1504.6	5.17	1.51	1330.1
100.00	0.00	2555	79623	1.204	1.1120	88.682	324	.0293	3.352	1635.6	13.52	1.69	1514.5
300.00	0.00	2393	75231	1.254	1.1028	104.054	314	.0333	3.835	1736.6	33.78	1.83	1635.8
1000.00	0.00	2241	70906	1.309	1.0950	117.246	305	.0363	4.339	1831.8	94.64	1.95	1747.0
3000.00	0.00	2120	67337	1.358	1.0892	126.107	297	.0380	4.783	1907.4	246.57	2.05	1833.8
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	4400	105157	1.019	1.4158	8.246	436	0.0046					
1.80	0.82	3884	100475	1.040	1.2611	16.102	405	.0074	1.000	1144.4	1.00	0.70	638.2
3.00	0.49	3658	96868	1.062	1.2050	25.179	389	.0106	1.428	1195.1	1.13	0.93	849.3
10.00	0.15	3183	89451	1.120	1.1526	47.743	365	.0182	2.197	1379.2	2.30	1.28	1169.0
30.00	0.05	2912	83653	1.174	1.1314	66.439	350	.0239	2.776	1524.6	5.16	1.50	1367.8
100.00	0.01	2679	78103	1.232	1.1168	83.645	336	.0287	3.349	1656.8	13.43	1.68	1554.3
300.00	0.00	2502	73613	1.285	1.1072	96.180	326	.0319	3.838	1758.3	33.42	1.82	1676.7
1000.00	0.00	2336	69211	1.343	1.0990	106.532	316	.0342	4.350	1853.6	93.37	1.94	1788.5
3000.00	0.00	2204	65592	1.395	1.0929	113.042	307	.0352	4.802	1929.1	242.28	2.04	1855.4
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	4400	102989	1.040	1.2991	13.726	439	0.0070					
1.78	2.47	4007	98408	1.066	1.2269	22.427	416	.0103	1.000	1146.0	1.00	0.69	631.3
3.00	1.47	3752	94701	1.092	1.1936	28.939	402	.0133	1.426	1199.0	1.14	0.92	849.3
10.00	0.44	3326	87185	1.155	1.1544	50.097	379	.0198	2.187	1385.1	2.31	1.28	1172.7
30.00	0.15	3040	81319	1.212	1.1350	65.298	363	.0244	2.767	1531.1	5.16	1.50	1373.2
100.00	0.04	2780	75714	1.274	1.1207	78.830	349	.0281	3.345	1662.5	13.38	1.68	1560.3
300.00	0.01	2599	71199	1.330	1.1110	88.267	337	.0303	3.839	1764.8	33.18	1.81	1683.2
1000.00	0.00	2420	66788	1.391	1.1026	95.527	326	.0317	4.358	1859.6	92.31	1.93	1774.8
3000.00	0.00	2278	63173	1.446	1.0963	99.489	317	.0320	4.817	1934.5	239.10	2.03	1861.3
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	4400	97059	1.101	1.2271	25.260	447	0.0123					
1.77	8.31	4097	92751	1.133	1.1991	32.737	431	.0150	1.000	1123.0	1.00	0.68	612.3
3.00	4.90	3866	89113	1.163	1.1810	39.423	418	.0173	1.427	1177.2	1.14	0.92	831.5
10.00	1.47	3449	81817	1.231	1.1536	53.059	396	.0217	2.179	1361.9	2.32	1.27	1151.6
30.00	0.49	3153	75115	1.294	1.1371	63.086	379	.0246	2.758	1506.1	5.18	1.49	1350.0
100.00	0.15	2888	70675	1.361	1.1238	71.274	363	.0265	3.337	1636.3	13.40	1.68	1515.2
300.00	0.05	2684	66306	1.421	1.1144	76.236	351	.0273	3.835	1735.6	33.13	1.81	1635.8
1000.00	0.01	2491	62050	1.487	1.1061	79.055	338	.0273	4.360	1828.4	91.86	1.93	1745.4
3000.00	0.00	2338	58575	1.546	1.0996	79.370	328	.0265	4.825	1901.4	237.24	2.03	1829.9
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	4400	87280	1.219	1.2002	34.528	462	0.0168					
1.76	25.03	4134	83403	1.255	1.1846	39.158	447	.0184	1.000	1071.1	1.00	0.67	580.8
3.00	14.70	3916	80055	1.289	1.1726	43.086	435	.0196	1.429	1124.2	1.15	0.92	792.9
10.00	4.41	3506	73371	1.364	1.1517	50.280	412	.0214	2.175	1302.1	2.33	1.27	1100.1
30.00	1.47	3204	68127	1.432	1.1377	54.722	394	.0222	2.751	1440.5	5.20	1.49	1290.6
100.00	0.44	2928	63146	1.505	1.1257	57.292	377	.0222	3.330	1565.2	13.44	1.68	1449.1
300.00	0.15	2712	59143	1.570	1.1171	57.619	362	.0214	3.831	1660.1	33.16	1.81	1564.7
1000.00	0.04	2507	55255	1.640	1.1095	55.885	348	.0199	4.359	1748.5	91.68	1.93	1669.3
3000.00	0.01	2341	52090	1.702	1.1042	52.499	336	.0181	4.830	1817.8	236.00	2.03	1749.8
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	4400	74852	1.412	1.1899	32.482	482	0.0164					
1.76	83.61	4142	71511	1.451	1.1784	34.218	467	.0167	1.000	996.8	1.00	0.67	539.2
3.00	48.99	3924	68569	1.488	1.1690	35.489	454	.0168	1.429	1046.7	1.15	0.92	737.8
10.00	14.70	3505	62792	1.569	1.1519	36.990	428	.0165	2.172	1212.9	2.34	1.27	1024.4
30.00	4.90	3188	58245	1.642	1.1401	36.713	407	.0155	2.748	1341.7	5.21	1.49	1202.1
100.00	1.47	2892	53920	1.718	1.1304	34.668	386	.0139	3.328	1457.4	13.40	1.68	1349.1
300.00	0.49	2655	50466	1.786	1.1244	31.288	369	.0120	3.832	1544.9	32.91	1.81	1456.7
1000.00	0.15	2419	47134	1.856	1.1214	26.048	350	.0096	4.368	1625.6	90.23	1.93	1553.0
3000.00	0.05	2215	44451	1.915	1.1242	20.050	333	.0071	4.851	1687.9	229.53	2.02	1626.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	4400	65831	1.596	1.1890	24.184	497	0.0128					
1.76	250.34	4130	62871	1.635	1.1793	24.467	480	.0124	1.000	937.7	1.00	0.67	507.4
3.00	146.96	3900	60295	1.672	1.1714	24.426	466	.0120	1.428	984.5	1.15	0.92	694.0
10.00	44.09	3451	55168	1.753	1.1576	23.242	435	.0107	3.170	1139.9	2.30	1.27	963.2
30.00	14.70	3101	51173	1.823	1.1496	20.860	410	.0091	2.747	1259.6	5.16	1.49	1129.4
100.00	4.41	2759	47404	1.894	1.1474	16.945	383	.0070	3.331	1365.7	13.14	1.67	1266.3
300.00	1.47	2461	44440	1.951	1.1566	12.421	358	.0049	3.841	1444.2	31.69	1.80	1364.3
1000.00	0.44	2197	41667	1.997	1.2022	7.226	326	.0027	4.378	1512.9	83.15	1.92	1450.0
3000.00	0.15	1986	39586	2.014	1.3051	4.317	284	.0015	4.889	1559.6	192.07	2.00	1511.2
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	4400	59484	1.756	1.1946	16.204	509	0.0089					
1.76	833.48	4102	56785	1.793	1.1870	15.816	489	.0084	1.000	892.7	1.00	0.67	484.5
3.00	489.87	3847	54467	1.827	1.1814	15.208	471	.0078	1.424	936.3	1.14	0.92	660.7
10.00	146.96	3334	49860	1.897	1.1750	12.993	433	.0061	3.166	1081.1	2.30	1.27	915.1
30.00	48.99	2909	46323	1.953	1.1813	10.114	399	.0045	2.744	1190.5	5.01	1.49	1070.1
100.00	14.70	2442	43080	1.997	1.2180	6.642	358	.0028	3.329	1283.2	12.29	1.66	1194.7
300.00	4.90	1973	40875	2.014	1.2923	4.492	313	.0017	3.867	1345.5	27.59	1.78	1279.3
1000.00	1.47	1471	38638	2.016	1.3472	3.828	258	.0013	4.620	1393.6	65.09	1.87	1346.8
3000.00	0.49	1099	37254	2.016	1.3736	3.624	213	.0010	5.465	1424.7	141.29	1.93	1390.8

E-269

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(s) Chamber temperature, 4600° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	4600	107263	1.009	1.6409	5.115	447	0.0033					
1.89	0.08	3691	102132	1.015	1.4196	7.817	388	.0039	1.000	1138.9	1.00	0.75	668.2
3.00	0.05	3339	98980	1.028	1.2565	14.925	366	.0063	1.429	1179.7	1.11	0.96	848.9
10.00	0.01	2895	91951	1.077	1.1494	42.374	339	.0151	2.233	1355.6	2.26	1.30	1154.3
30.00	0.00	2654	86459	1.125	1.1234	67.417	325	.0226	2.811	1497.0	5.11	1.51	1345.4
100.00	0.00	2453	81158	1.178	1.1084	91.499	313	.0293	3.373	1626.6	13.44	1.70	1507.1
300.00	0.00	2302	76840	1.225	1.0993	109.909	304	.0340	3.850	1726.9	33.69	1.83	1627.0
1000.00	0.00	2161	72575	1.277	1.0917	126.179	296	.0378	4.347	1821.5	94.72	1.95	1737.3
3000.00	0.00	2048	69044	1.324	1.0862	137.612	289	.0402	4.785	1897.0	247.51	2.05	1823.6
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	4600	107122	1.010	1.5970	5.483	447	0.0035					
1.85	0.24	3813	102167	1.021	1.3510	9.889	397	.0049	1.000	1149.6	1.00	0.73	660.6
3.00	0.15	3484	98708	1.038	1.2352	17.993	377	.0076	1.429	1194.9	1.12	0.95	855.7
10.00	0.04	3038	91420	1.090	1.1526	43.503	351	.0160	2.218	1375.0	2.28	1.29	1168.9
30.00	0.01	2780	85736	1.140	1.1279	65.944	336	.0228	2.798	1518.6	5.12	1.51	1364.1
100.00	0.00	2562	80271	1.196	1.1128	87.223	324	.0289	3.367	1649.7	13.40	1.69	1528.5
300.00	0.00	2399	75838	1.246	1.1032	103.240	314	.0330	3.850	1750.8	33.48	1.83	1649.9
1000.00	0.00	2246	71475	1.300	1.0953	117.100	305	.0362	4.354	1846.0	93.81	1.95	1761.2
3000.00	0.00	2124	67875	1.349	1.0894	126.528	297	.0381	4.799	1921.6	244.44	2.04	1848.0
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	4600	106638	1.014	1.4941	6.729	447	0.0041					
1.82	0.81	3966	101695	1.032	1.2938	13.215	409	.0063	1.000	1162.6	1.00	0.71	655.8
3.00	0.49	3659	98065	1.053	1.2197	21.756	391	.0094	1.426	1211.7	1.13	0.94	863.7
10.00	0.15	3206	90503	1.109	1.1564	44.718	365	.0171	2.204	1395.8	2.28	1.29	1184.9
30.00	0.05	2927	84619	1.162	1.1331	64.178	350	.0231	2.787	1541.4	5.11	1.50	1384.7
100.00	0.01	2689	78987	1.221	1.1177	82.278	336	.0283	3.362	1673.9	13.31	1.68	1551.1
300.00	0.00	2510	74439	1.274	1.1078	95.603	326	.0317	3.852	1775.7	33.13	1.82	1673.8
1000.00	0.00	2343	69982	1.331	1.0994	106.766	315	.0342	4.365	1871.2	92.47	1.94	1785.9
3000.00	0.00	2211	66319	1.382	1.0932	113.962	307	.0355	4.818	1946.8	240.19	2.03	1873.0
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	4600	105321	1.027	1.3682	9.946	449	0.0055					
1.80	2.45	4107	100450	1.051	1.2500	17.880	421	.0085	1.000	1170.2	1.00	0.70	651.0
3.00	1.47	3821	96665	1.075	1.2078	26.252	405	.0115	1.424	1222.0	1.13	0.93	867.9
10.00	0.44	3362	88920	1.136	1.1591	46.358	380	.0184	2.194	1408.8	2.29	1.28	1194.6
30.00	0.15	3065	82903	1.192	1.1375	62.746	363	.0235	2.778	1555.8	5.11	1.50	1396.7
100.00	0.04	2808	77166	1.254	1.1221	77.602	348	.0277	3.358	1688.9	13.24	1.68	1565.2
300.00	0.01	2614	72551	1.310	1.1120	88.189	337	.0303	3.855	1790.8	32.83	1.81	1688.6
1000.00	0.00	2433	68047	1.370	1.1032	96.623	326	.0320	4.376	1886.2	91.70	1.93	1800.9
3000.00	0.00	2290	64358	1.424	1.0968	101.571	317	.0327	4.836	1961.5	236.47	2.02	1887.9
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	4600	101368	1.066	1.2655	18.183	455	0.0093					
1.78	8.25	4232	96691	1.096	1.2197	26.108	435	.0123	1.000	1161.0	1.00	0.68	638.0
3.00	4.90	3969	92868	1.124	1.1944	33.404	421	.0150	1.424	1214.9	1.14	0.92	860.0
10.00	1.47	3514	85155	1.191	1.1598	49.134	396	.0203	2.184	1402.5	2.30	1.28	1187.7
30.00	0.49	3202	79161	1.252	1.1408	61.205	379	.0239	2.768	1549.1	5.12	1.49	1390.1
100.00	0.15	2927	73462	1.318	1.1261	71.555	363	.0266	3.352	1681.4	13.22	1.67	1558.3
300.00	0.05	2717	68895	1.378	1.1160	78.358	350	.0280	3.854	1782.4	32.66	1.80	1681.0
1000.00	0.01	2521	64453	1.442	1.1071	83.031	338	.0286	4.382	1876.5	90.51	1.92	1792.2
3000.00	0.00	2365	60829	1.500	1.1006	84.893	328	.0283	4.849	1950.7	233.69	2.02	1878.1
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	4600	93621	1.151	1.2209	28.666	467	0.0143					
1.77	24.91	4293	89310	1.186	1.1991	34.567	450	.0165	1.000	1123.3	1.00	0.68	612.5
3.00	14.70	4051	85672	1.218	1.1836	39.684	438	.0182	1.426	1177.4	1.14	0.92	831.7
10.00	4.41	3606	78386	1.292	1.1581	49.732	413	.0213	2.178	1361.0	2.31	1.27	1151.4
30.00	1.47	3286	72714	1.358	1.1419	56.688	395	.0230	2.760	1503.9	5.14	1.49	1348.8
100.00	0.46	2998	67324	1.429	1.1284	61.822	377	.0239	3.344	1632.5	13.26	1.67	1512.7
300.00	0.15	2776	63014	1.493	1.1188	64.293	363	.0239	3.849	1730.4	32.68	1.81	1631.9
1000.00	0.04	2566	58834	1.562	1.1104	64.693	349	.0231	4.381	1821.4	90.29	1.92	1739.8
3000.00	0.01	2399	55433	1.624	1.1042	63.067	338	.0218	4.855	1892.9	232.46	2.02	1822.9
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	4600	81389	1.319	1.2019	32.499	486	0.0167					
1.76	83.35	4316	77636	1.357	1.1878	35.337	471	.0174	1.000	1052.5	1.00	0.67	571.5
3.00	48.99	4082	74413	1.393	1.1767	37.612	457	.0180	1.427	1104.2	1.15	0.92	779.1
10.00	14.70	3637	67981	1.473	1.1567	41.312	431	.0185	2.174	1277.7	2.32	1.27	1080.1
30.00	4.90	3306	62965	1.545	1.1429	42.896	410	.0182	2.754	1412.3	5.16	1.49	1266.5
100.00	1.47	3002	58204	1.622	1.1313	42.698	390	.0172	3.338	1533.0	13.28	1.67	1420.4
300.00	0.49	2764	54406	1.690	1.1232	40.823	374	.0158	3.845	1624.6	32.62	1.81	1532.3
1000.00	0.15	2534	50737	1.763	1.1167	37.012	357	.0137	4.384	1709.3	89.71	1.93	1633.1
3000.00	0.05	2344	47770	1.826	1.1134	32.037	342	.0114	4.865	1775.3	229.51	2.02	1710.4
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	4600	79929	1.506	1.1966	26.563	504	0.0142					
1.76	250.26	4313	67535	1.547	1.1852	27.483	487	.0141	1.000	985.6	1.00	0.67	534.6
3.00	146.96	4072	64803	1.584	1.1759	28.024	472	.0139	1.427	1034.2	1.15	0.92	729.5
10.00	44.09	3606	59159	1.667	1.1591	28.072	442	.0130	2.172	1196.5	2.32	1.27	1011.5
30.00	14.70	3253	54767	1.739	1.1480	26.690	418	.0117	2.752	1321.9	5.14	1.49	1185.5
100.00	4.41	2919	50617	1.816	1.1402	23.675	394	.0098	3.339	1433.7	13.16	1.67	1329.1
300.00	1.47	2645	47333	1.880	1.1380	19.658	372	.0078	3.851	1517.5	32.04	1.80	1432.6
1000.00	0.44	2357	44204	1.944	1.1458	14.117	348	.0053	4.399	1593.4	86.52	1.92	1524.7
3000.00	0.15	2075	41741	1.990	1.1798	8.633	322	.0031	4.886	1650.0	213.61	2.01	1593.4
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	4600	62934	1.690	1.1983	18.292	519	0.0102					
1.76	832.93	4291	60000	1.728	1.1890	18.218	499	.0098	1.000	930.1	1.00	0.67	505.2
3.00	489.87	4030	57488	1.763	1.1817	17.887	481	.0092	1.425	975.4	1.14	0.92	688.4
10.00	146.96	3514	52487	1.840	1.1701	16.210	445	.0078	2.169	1126.6	2.31	1.27	953.4
30.00	48.99	3105	48631	1.904	1.1671	13.611	414	.0061	2.750	1242.0	5.05	1.49	1115.6
100.00	14.70	2686	45050	1.963	1.1788	9.870	380	.0042	3.341	1342.2	13.64	1.66	1247.4
300.00	4.90	2284	42311	2.001	1.2228	6.364	343	.0026	3.856	1413.3	29.49	1.79	1339.6
1000.00	1.47	1785	39884	2.015	1.3130	4.195	293	.0015	4.466	1470.3	72.12	1.89	1416.2
3000.00	0.49	1353	38192	2.016	1.3556	3.759	244	.0012	5.231	1506.8	158.29	1.96	1467.3

E-692

CT-5

TABLE I. - Continued. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(t) Chamber temperature, 4800° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	4800	108277	1.008	1.6523	5.032	459	0.0034					
1.92	0.08	3782	102804	1.013	1.4746	6.836	394	.0036	1.000	1158.0	1.00	0.77	690.1
3.00	0.05	3392	99706	1.024	1.2866	12.611	369	.0055	1.423	1195.3	1.10	0.96	863.6
10.00	0.01	2910	92577	1.071	1.1532	39.648	339	.0142	2.246	1369.7	2.23	1.30	1168.8
30.00	0.00	2663	87033	1.119	1.1248	65.158	325	.0218	2.826	1510.9	5.04	1.51	1359.6
100.00	0.00	2459	81688	1.171	1.1091	89.874	313	.0288	3.390	1640.4	13.25	1.69	1521.0
300.00	0.00	2307	77338	1.219	1.0997	108.862	304	.0337	3.868	1740.5	33.24	1.82	1640.8
1000.00	0.00	2165	73042	1.271	1.0920	125.736	296	.0377	4.366	1835.1	93.48	1.95	1751.0
3000.00	0.00	2052	69486	1.317	1.0864	137.685	288	.0402	4.804	1910.5	244.30	2.04	1837.7
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	4800	108192	1.009	1.6261	5.238	459	0.0035					
1.88	0.23	3895	102873	1.017	1.3978	8.445	402	.0043	1.000	1167.0	1.00	0.75	680.3
3.00	0.15	3531	99506	1.032	1.2562	15.525	380	.0068	1.428	1209.6	1.11	0.95	869.3
10.00	0.04	3054	92113	1.084	1.1561	40.937	351	.0151	2.228	1388.8	2.25	1.30	1182.8
30.00	0.01	2789	86370	1.134	1.1293	63.887	336	.0222	2.811	1532.4	5.07	1.51	1378.0
100.00	0.00	2569	80855	1.188	1.1135	85.813	324	.0284	3.381	1663.4	13.26	1.69	1542.3
300.00	0.00	2404	76384	1.238	1.1037	102.416	314	.0327	3.865	1764.5	33.14	1.82	1663.6
1000.00	0.00	2250	71986	1.292	1.0956	116.884	305	.0361	4.371	1859.7	92.87	1.94	1774.0
3000.00	0.00	2128	68358	1.341	1.0896	125.828	297	.0382	4.816	1935.4	242.04	2.04	1861.7
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	4800	109896	1.012	1.5544	5.942	460	0.0038					
1.84	0.80	4046	102685	1.026	1.3295	11.108	414	.0056	1.000	1179.7	1.00	0.72	673.3
3.00	0.49	3728	99052	1.045	1.2356	18.983	393	.0084	1.425	1226.9	1.12	0.94	877.3
10.00	0.15	3225	91365	1.101	1.1599	42.131	366	.0162	2.213	1410.6	2.26	1.29	1199.4
30.00	0.05	2939	85405	1.154	1.1346	62.197	350	.0225	2.798	1556.4	5.07	1.50	1399.0
100.00	0.01	2698	79709	1.212	1.1185	81.029	336	.0279	3.375	1689.0	13.20	1.68	1566.1
300.00	0.00	2517	75112	1.264	1.1083	95.005	325	.0315	3.866	1790.9	32.85	1.81	1689.0
1000.00	0.00	2349	70611	1.321	1.0998	106.841	315	.0342	4.381	1886.6	91.68	1.93	1801.2
3000.00	0.00	2216	66912	1.373	1.0935	114.605	307	.0357	4.834	1962.3	238.18	2.03	1888.4
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	4800	127078	1.019	1.4404	7.834	461	0.0047					
1.81	2.43	4197	101937	1.040	1.2527	14.722	425	.0072	1.000	1190.2	1.00	0.71	668.8
3.00	1.47	3880	98106	1.063	1.2310	22.749	407	.0102	1.423	1240.7	1.13	0.93	883.6
10.00	0.44	3330	90184	1.123	1.1632	43.390	380	.0173	2.200	1427.7	2.27	1.28	1212.5
30.00	0.15	3083	84054	1.179	1.1394	60.622	363	.0227	2.788	1575.2	5.06	1.50	1415.4
100.00	0.04	2822	78219	1.240	1.1234	76.447	348	.0273	3.371	1708.8	13.12	1.68	1584.7
300.00	0.01	2625	73592	1.295	1.1127	87.885	337	.0302	3.869	1811.1	32.59	1.81	1708.5
1000.00	0.00	2443	68959	1.355	1.1037	97.190	326	.0322	4.391	1906.8	90.44	1.93	1821.2
3000.00	0.00	2298	65217	1.409	1.0971	102.872	316	.0331	4.853	1982.4	234.25	2.02	1908.5
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	4800	104480	1.044	1.3149	13.278	465	0.0072					
1.79	8.19	4346	99476	1.072	1.2427	21.036	440	.0102	1.000	1190.9	1.00	0.69	659.8
3.00	4.90	4055	95527	1.096	1.2080	28.507	424	.0130	1.422	1244.0	1.13	0.93	882.6
10.00	1.47	3564	87501	1.165	1.1652	45.564	397	.0189	2.189	1433.1	2.28	1.28	1215.5
30.00	0.49	3237	81296	1.225	1.1438	59.074	379	.0231	2.778	1581.2	5.06	1.49	1420.3
100.00	0.15	2954	75411	1.290	1.1280	70.987	363	.0264	3.366	1714.9	13.06	1.67	1590.4
300.00	0.05	2740	70764	1.349	1.1172	79.136	350	.0283	3.870	1816.8	32.26	1.80	1714.3
1000.00	0.01	2541	66131	1.413	1.1080	85.174	338	.0293	4.401	1911.8	89.37	1.92	1826.7
3000.00	0.00	2383	62403	1.470	1.1011	88.177	328	.0294	4.871	1986.7	230.71	2.01	1913.4
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	4800	98724	1.104	1.2481	22.442	473	0.0116					
1.78	24.78	4438	94010	1.138	1.2160	28.164	454	.0142	1.000	1167.1	1.00	0.68	640.4
3.00	14.70	4170	90138	1.168	1.1956	33.106	440	.0163	1.423	1221.4	1.14	0.92	864.4
10.00	4.41	3687	82349	1.240	1.1645	47.427	414	.0204	2.181	1409.1	2.29	1.27	1193.7
30.00	1.47	3349	76319	1.305	1.1459	56.482	395	.0230	2.769	1555.2	5.08	1.49	1396.3
100.00	0.44	3050	70610	1.375	1.1310	63.795	377	.0247	3.358	1686.7	13.08	1.67	1564.0
300.00	0.15	2822	66056	1.439	1.1205	68.106	363	.0253	3.867	1786.6	32.21	1.80	1686.0
1000.00	0.04	2608	61645	1.506	1.1115	70.349	350	.0251	4.403	1879.6	88.94	1.92	1796.2
3000.00	0.01	2438	58062	1.567	1.1047	70.251	338	.0242	4.879	1952.5	228.93	2.01	1881.0
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	4800	87702	1.240	1.2168	30.294	491	0.0158					
1.77	83.03	4483	83522	1.278	1.1992	34.237	474	.0171	1.000	1106.0	1.00	0.68	603.1
3.00	48.99	4230	79996	1.313	1.1858	37.516	460	.0181	1.425	1159.0	1.14	0.92	818.8
10.00	14.70	3753	72946	1.392	1.1623	43.507	433	.0196	2.176	1338.9	2.31	1.27	1133.1
30.00	4.90	3406	67475	1.462	1.1466	47.064	412	.0201	2.761	1478.4	5.11	1.49	1326.7
100.00	1.47	3092	62299	1.538	1.1334	48.852	392	.0198	3.350	1603.6	13.12	1.67	1486.7
300.00	0.49	2848	58178	1.606	1.1240	48.622	376	.0188	3.861	1698.5	32.23	1.80	1602.8
1000.00	0.15	2617	54199	1.679	1.1160	46.425	360	.0172	4.402	1786.3	88.68	1.92	1707.4
3000.00	0.05	2431	50980	1.743	1.1105	42.746	346	.0153	4.885	1855.0	227.27	2.01	1787.5
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	4800	76389	1.420	1.2062	27.943	510	0.0151					
1.77	249.61	4491	72744	1.460	1.1928	29.602	492	.0154	1.000	1035.4	1.00	0.68	563.2
3.00	146.96	4236	69638	1.497	1.1820	30.813	477	.0155	1.425	1085.6	1.14	0.92	766.4
10.00	44.09	3748	63441	1.580	1.1625	32.318	447	.0151	2.174	1254.6	2.31	1.27	1061.5
30.00	14.70	3384	58631	1.654	1.1491	32.158	424	.0142	2.757	1385.3	5.11	1.49	1243.0
100.00	4.41	3048	54092	1.733	1.1384	30.325	400	.0127	3.348	1502.1	13.09	1.67	1392.9
300.00	1.47	2780	50493	1.801	1.1319	27.212	381	.0108	3.862	1590.0	31.98	1.80	1501.1
1000.00	0.44	2515	47045	1.872	1.1294	22.344	360	.0085	4.411	1670.6	87.18	1.92	1597.9
3000.00	0.15	2284	44280	1.930	1.1344	16.765	341	.0061	4.906	1732.5	220.17	2.00	1671.3
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	4800	66791	1.618	1.2040	20.243	528	0.0115					
1.77	831.88	4476	63591	1.658	1.1930	20.548	508	.0111	1.000	970.0	1.00	0.68	527.7
3.00	489.87	4206	60867	1.695	1.1843	20.558	490	.0108	1.424	1016.8	1.14	0.92	718.0
10.00	146.96	3679	55440	1.775	1.1690	19.584	455	.0095	2.172	1174.1	2.30	1.27	993.9
30.00	48.99	3274	51251	1.845	1.1607	17.501	425	.0080	2.755	1294.8	5.06	1.49	1162.9
100.00	14.70	2879	47337	1.914	1.1598	14.027	395	.0060	3.350	1401.0	12.79	1.67	1301.1
300.00	4.90	2532	44293	1.967	1.1739	10.070	366	.0041	3.871	1478.7	30.54	1.79	1399.2
1000.00	1.47	2116	41488	2.005	1.2339	5.897	327	.0023	4.422	1545.3	78.68	1.90	1483.8
3000.00	0.49	1672	39430	2.015	1.3232	4.075	281	.0014	5.069	1589.5	178.47	1.97	1543.0

TABLE I. - Concluded. THEORETICAL PERFORMANCE OF HYDROGEN AS A ROCKET PROPELLANT AT ASSIGNED PRESSURE RATIOS FROM 1 TO 3000

[Equilibrium composition during isentropic expansion from chamber conditions.]

(u) Chamber temperature, 5000° K

Pressure ratio, P_c/P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, $\mathcal{M}$	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, k, $\frac{cal}{(sec)(°K)(cm)}$	Mach number, M	Specific impulse in vacuum, I_{vac}, $\frac{(lb)(sec)}{lb}$	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, $\frac{(lb)(sec)}{lb}$
Chamber pressure, P_c, 0.146960 lb/sq in. abs													
1.00	0.15	5000	109279	1.008	1.6584	4.988	471	0.0035					
1.90	0.08	3882	103458	1.011	1.5257	6.160	401	.0034	1.000	1178.1	1.00	0.78	711.6
3.00	0.05	3452	100405	1.020	1.3243	10.630	372	.0048	1.411	1211.7	1.09	0.96	878.7
10.00	0.01	2926	93174	1.056	1.1574	37.013	340	.0133	2.259	1384.3	2.19	1.30	1183.8
30.00	0.00	2671	87578	1.113	1.1262	62.939	325	.0211	2.843	1525.1	4.96	1.51	1374.1
100.00	0.00	2464	82192	1.165	1.1098	88.253	313	.0282	3.408	1654.3	13.05	1.68	1535.2
300.00	0.00	2311	77810	1.213	1.1001	107.793	304	.0334	3.887	1754.3	32.73	1.81	1654.8
1000.00	0.00	2168	73485	1.264	1.0922	125.246	295	.0375	4.385	1848.8	92.06	1.93	1764.8
3000.00	0.00	2055	69906	1.311	1.0866	137.680	288	.0402	4.824	1924.1	240.67	2.03	1850.9
Chamber pressure, P_c, 0.440880 lb/sq in. abs													
1.00	0.44	5000	109225	1.009	1.6427	5.104	471	0.0035					
1.91	0.23	3983	103582	1.015	1.4466	7.380	408	.0040	1.000	1185.1	1.00	0.76	700.7
3.00	0.15	3583	100255	1.027	1.2815	13.357	383	.0060	1.421	1224.7	1.10	0.96	883.4
10.00	0.04	3070	92759	1.078	1.1598	38.496	352	.0143	2.239	1402.8	2.22	1.30	1197.0
30.00	0.01	2799	86959	1.127	1.1337	61.897	336	.0215	2.825	1546.1	5.01	1.51	1391.9
100.00	0.00	2575	81398	1.182	1.1141	84.423	324	.0279	3.397	1677.1	13.11	1.69	1556.1
300.00	0.00	2409	76892	1.232	1.1041	101.574	314	.0325	3.882	1778.1	32.75	1.82	1677.3
1000.00	0.00	2254	72461	1.285	1.0958	116.610	304	.0360	4.388	1873.3	91.80	1.94	1788.5
3000.00	0.00	2131	68828	1.334	1.0878	127.039	297	.0382	4.834	1949.0	239.29	2.03	1878.2
Chamber pressure, P_c, 1.46960 lb/sq in. abs													
1.00	1.47	5000	109038	1.010	1.5936	5.571	472	0.0037					
1.86	0.79	4129	103545	1.022	1.3694	9.516	418	.0050	1.000	1196.7	1.00	0.74	691.4
3.00	0.49	3757	99922	1.039	1.2532	16.519	386	.0075	1.423	1241.7	1.12	0.95	890.7
10.00	0.15	3244	92119	1.093	1.1634	39.793	365	.0154	2.221	1424.7	2.24	1.29	1213.4
30.00	0.05	2951	86091	1.146	1.1351	60.270	350	.0218	2.810	1570.6	5.02	1.50	1413.0
100.00	0.01	2706	80339	1.204	1.1134	79.840	336	.0275	3.388	1703.3	13.08	1.68	1580.3
300.00	0.00	2524	75700	1.256	1.1098	94.391	325	.0313	3.881	1805.2	32.55	1.81	1703.2
1000.00	0.00	2354	71159	1.313	1.1001	106.818	315	.0342	4.396	1900.9	90.87	1.93	1815.5
3000.00	0.00	2220	67429	1.364	1.0937	115.085	307	.0358	4.850	1976.7	238.07	2.02	1902.8
Chamber pressure, P_c, 4.40880 lb/sq in. abs													
1.00	4.41	5000	109516	1.015	1.5246	6.654	472	0.0043					
1.83	2.41	4282	103107	1.033	1.3132	12.424	412	.0063	1.000	1208.4	1.00	0.72	686.0
3.00	1.47	3934	99262	1.054	1.2365	19.964	410	.0091	1.421	1257.2	1.13	0.94	897.8
10.00	0.44	3414	91182	1.113	1.1670	40.908	381	.0154	2.208	1444.1	2.25	1.28	1228.1
30.00	0.15	3095	84961	1.168	1.1412	58.749	363	.0221	2.799	1591.8	5.03	1.50	1431.6
100.00	0.04	2833	79944	1.229	1.1242	75.380	348	.0269	3.383	1725.7	13.01	1.67	1601.2
300.00	0.01	2674	74304	1.284	1.1133	87.497	337	.0301	3.883	1828.2	32.24	1.80	1725.4
1000.00	0.00	2455	69677	1.341	1.1041	97.501	325	.0333	4.406	1924.1	89.65	1.92	1838.3
3000.00	0.00	2305	66832	1.394	1.0974	103.771	315	.0353	4.869	1999.9	232.93	2.01	1925.8
Chamber pressure, P_c, 14.6960 lb/sq in. abs													
1.00	14.70	5000	106798	1.031	1.3725	10.152	475	0.0059					
1.81	8.13	4455	101407	1.057	1.2677	17.340	444	.0087	1.000	1215.1	1.00	0.70	679.2
3.00	4.90	4128	97444	1.082	1.2216	24.711	427	.0115	1.420	1267.1	1.13	0.93	901.2
10.00	1.47	3602	89198	1.146	1.1700	42.583	398	.0178	2.195	1457.0	2.26	1.28	1237.5
30.00	0.49	3264	82835	1.204	1.1464	57.120	379	.0224	2.788	1606.1	5.02	1.49	1444.0
100.00	0.15	2974	76815	1.270	1.1294	70.180	363	.0261	3.379	1749.5	12.93	1.67	1615.2
300.00	0.05	2757	72005	1.329	1.1182	79.427	350	.0284	3.885	1843.0	31.92	1.80	1740.0
1000.00	0.01	2555	67338	1.392	1.1086	86.380	339	.0297	4.418	1938.6	88.41	1.91	1853.0
3000.00	0.00	2396	63535	1.446	1.1016	90.234	328	.0301	4.889	2013.9	228.20	2.00	1940.2
Chamber pressure, P_c, 44.0880 lb/sq in. abs													
1.00	44.09	5000	102665	1.073	1.2827	17.184	481	0.0093					
1.79	24.62	4631	97586	1.104	1.2351	24.232	453	.0121	1.000	1203.0	1.00	0.69	664.8
3.00	14.70	4274	93636	1.134	1.2083	30.626	443	.0145	1.420	1256.9	1.13	0.92	891.3
10.00	4.41	3752	85343	1.204	1.1704	44.588	415	.0193	2.186	1447.2	2.27	1.27	1227.7
30.00	1.47	3398	79035	1.267	1.1494	56.266	395	.0226	2.778	1595.6	5.03	1.49	1433.9
100.00	0.44	3068	73081	1.336	1.1332	66.302	377	.0249	3.372	1728.9	12.92	1.67	1604.4
300.00	0.15	2855	68341	1.399	1.1221	70.083	363	.0261	3.884	1830.3	31.78	1.79	1728.5
1000.00	0.04	2637	63757	1.466	1.1125	73.805	350	.0264	4.423	1924.5	87.72	1.91	1840.0
3000.00	0.01	2465	60036	1.526	1.1053	74.938	338	.0259	4.902	1998.5	225.73	2.00	1926.0
Chamber pressure, P_c, 146.960 lb/sq in. abs													
1.00	146.96	5000	93403	1.178	1.2353	26.536	496	0.0142					
1.76	82.67	4642	88820	1.215	1.2123	31.445	477	.0159	1.000	1154.9	1.00	0.68	632.9
3.00	48.99	4366	84999	1.248	1.1959	35.608	463	.0173	1.422	1208.7	1.14	0.92	855.1
10.00	14.70	3854	77374	1.326	1.1683	43.752	434	.0198	2.179	1393.8	2.29	1.27	1181.0
30.00	4.90	3499	71488	1.395	1.1555	49.709	413	.0210	2.769	1537.4	5.05	1.49	1380.9
100.00	1.47	3163	65940	1.470	1.1359	52.937	394	.0215	3.363	1666.2	12.96	1.67	1545.8
300.00	0.49	2914	61533	1.537	1.1255	54.328	379	.0211	3.878	1763.7	31.80	1.79	1665.3
1000.00	0.15	2679	57283	1.609	1.1165	53.739	362	.0200	4.423	1854.0	87.47	1.91	1772.8
3000.00	0.05	2492	53846	1.674	1.1100	51.378	349	.0184	4.908	1924.6	224.36	2.00	1855.9
Chamber pressure, P_c, 440.880 lb/sq in. abs													
1.00	440.88	5000	82010	1.340	1.2179	28.035	515	0.0154					
1.77	248.84	4663	77972	1.380	1.2019	30.498	497	.0160	1.000	1085.6	1.00	0.68	592.6
3.00	146.95	4392	74587	1.417	1.1895	32.437	481	.0164	1.423	1137.2	1.14	0.92	803.7
10.00	44.09	3877	67815	1.499	1.1670	35.555	451	.0167	2.176	1312.5	2.30	1.27	1111.6
30.00	14.70	3499	62581	1.573	1.1517	36.773	427	.0164	2.763	1448.1	5.07	1.49	1300.2
100.00	4.41	3155	57651	1.652	1.1391	36.311	405	.0153	3.358	1569.2	12.97	1.67	1455.9
300.00	1.47	2886	53746	1.722	1.1305	34.310	386	.0138	3.875	1660.6	31.73	1.80	1568.3
1000.00	0.44	2628	49998	1.796	1.1241	30.472	367	.0116	4.426	1744.8	86.77	1.91	1669.0
3000.00	0.15	2413	46988	1.860	1.1217	28.583	350	.0094	4.920	1809.9	220.75	2.00	1745.7
Chamber pressure, P_c, 1469.60 lb/sq in. abs													
1.00	1469.60	5000	71011	1.545	1.2112	21.884	536	0.0125					
1.77	830.33	4657	67613	1.586	1.1986	22.630	515	.0124	1.000	1011.9	1.00	0.68	551.7
3.00	489.87	4375	64563	1.623	1.1885	23.037	498	.0122	1.423	1060.2	1.14	0.92	749.0
10.00	146.96	3832	58675	1.706	1.1702	22.915	462	.0112	2.173	1223.5	2.30	1.27	1036.1
30.00	48.99	3422	54135	1.779	1.1586	21.520	434	.0099	2.760	1349.0	5.05	1.49	1211.8
100.00	14.70	3036	49886	1.854	1.1515	18.625	406	.0081	3.358	1460.2	12.81	1.66	1355.8
300.00	4.90	2716	46557	1.916	1.1525	14.875	380	.0061	3.881	1542.7	30.94	1.79	1458.7
1000.00	1.47	2370	43427	1.973	1.1716	9.947	350	.0039	4.441	1616.3	82.28	1.90	1549.2
3000.00	0.49	2010	41019	2.006	1.2362	5.799	316	.0022	4.937	1669.1	197.44	1.98	1615.5

E-692

E-692

CT-5, back

TABLE II. - EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(a) Chamber temperature, T_c, 1200° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 4.4080 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	1200		1.00000
1.88	1011		1.00000
3.00	888		1.00000
10.00	633		1.00000
30.00	463		1.00000
100.00	329		1.00000
300.00	239		1.00000
1000.00	165		1.00000
3000.00	115		1.00000

(b) Chamber temperature, T_c, 1400° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	1400	0.00005	0.99996
1.87	1186		1.00000
3.00	1044		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 4.4080 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	1400	0.00003	0.99998
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	1400	0.00002	0.99999
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	1400		1.00000
1.87	1185		1.00000
3.00	1043		1.00000
10.00	746		1.00000
30.00	547		1.00000
100.00	388		1.00000
300.00	283		1.00000
1000.00	198		1.00000
3000.00	140		1.00000

(c) Chamber temperature, T_c, 1600° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	1600	0.00054	0.99946
1.87	1365	.00004	.99996
3.00	1204		1.00000
10.00	865		1.00000
30.00	635		1.00000
100.00	451		1.00000
300.00	330		1.00000
1000.00	233		1.00000
3000.00	166		1.00000
P_c, 4.4080 lb/sq in. abs			
1.00	1600	0.00010	0.99990
1.87	1362	.00001	.99999
3.00	1201		1.00000
10.00	863		1.00000
30.00	634		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1600		0.99999
1.87	1362		1.00000
3.00	1201		1.00000
10.00	863		1.00000
30.00	633		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	1600	0.00031	0.99969
1.87	1364	.00002	.99998
3.00	1203		1.00000
10.00	864		1.00000
30.00	634		1.00000
100.00	451		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	166		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	1600	0.00005	0.99996
1.87	1362		1.00000
3.00	1201		1.00000
10.00	863		1.00000
30.00	634		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	1600		1.00000
1.87	1362		1.00000
3.00	1201		1.00000
10.00	863		1.00000
30.00	633		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	1600	0.00017	0.99983
1.87	1363	.00001	.99999
3.00	1202		1.00000
10.00	864		1.00000
30.00	634		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	166		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	1600	0.00003	0.99998
1.87	1362		1.00000
3.00	1201		1.00000
10.00	863		1.00000
30.00	633		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	1600		1.00000
1.87	1362		1.00000
3.00	1201		1.00000
10.00	863		1.00000
30.00	633		1.00000
100.00	450		1.00000
300.00	329		1.00000
1000.00	232		1.00000
3000.00	165		1.00000

TABLE II. - Continued. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(d) Chamber temperature, T_c, 1800° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.14490 lb/sq in. abs			
1.00	1800	0.00356	0.99644
1.85	1560	.00048	.99952
3.00	1380	.00006	.99995
10.00	999		1.00000
30.00	735		1.00000
100.00	523		1.00000
300.00	382		1.00000
1000.00	271		1.00000
3000.00	195		1.00000
P_c, 4.4[illegible] lb/sq in. abs			
1.00	1800	0.00065	0.99935
1.86	1543	.00007	.99993
3.00	1364		1.00000
10.00	986		1.00000
30.00	725		1.00000
100.00	516		1.00000
300.00	377		1.00000
1000.00	267		1.00000
3000.00	192		1.00000
P_c, 14[illegible] lb/sq in. abs			
1.00	1800	0.00011	0.99989
1.86	1540	.00001	.99999
3.00	1361		1.00000
10.00	984		1.00000
30.00	724		1.00000
100.00	514		1.00000
300.00	376		1.00000
1000.00	266		1.00000
3000.00	192		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.44080 lb/sq in. abs			
1.00	1800	0.00206	0.99794
1.86	1551	.00025	.99975
3.00	1372	.00003	.99998
10.00	992		1.00000
30.00	730		1.00000
100.00	519		1.00000
300.00	380		1.00000
1000.00	269		1.00000
3000.00	194		1.00000
P_c, 14.[illegible] lb/sq in. abs			
1.00	1800	0.00036	.99964
1.86	1541	.00004	.99996
3.00	1362		1.00000
10.00	985		1.00000
30.00	724		1.00000
100.00	515		1.00000
300.00	377		1.00000
1000.00	267		1.00000
3000.00	192		1.00000
P_c, 440.[illegible] lb/sq in. abs			
1.00	1800	0.00007	0.99993
1.86	1540	.00001	.99999
3.00	1360		1.00000
10.00	983		1.00000
30.00	723		1.00000
100.00	514		1.00000
300.00	376		1.00000
1000.00	266		1.00000
3000.00	192		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	1800	0.00113	0.99887
1.86	1546	.00013	.99987
3.00	1366	.00002	.99999
10.00	988		1.00000
30.00	727		1.00000
100.00	517		1.00000
300.00	378		1.00000
1000.00	268		1.00000
3000.00	193		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	1800	0.00021	0.99979
1.86	1541	.00002	.99998
3.00	1361		1.00000
10.00	984		1.00000
30.00	724		1.00000
100.00	515		1.00000
300.00	377		1.00000
1000.00	266		1.00000
3000.00	192		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	1800	0.00004	0.99997
1.86	1540		1.00000
3.00	1360		1.00000
10.00	983		1.00000
30.00	723		1.00000
100.00	514		1.00000
300.00	376		1.00000
1000.00	266		1.00000
3000.00	192		1.00000

(e) Chamber temperature, T_c, 2000° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.[illegible] lb/sq in. abs			
1.00	2000	0.01606	0.98394
1.81	1798	.00470	.99530
3.00	1608	.00102	.99899
10.00	1179		1.00000
30.00	872		1.00000
100.00	621		1.00000
300.00	455		1.00000
1000.00	323		1.00000
3000.00	234		1.00000
[illegible]			
1.00	2000	0.00295	0.99705
1.85	1734	.00050	.99950
3.00	1537	.00009	.99992
10.00	1119		1.00000
30.00	826		1.00000
100.00	588		1.00000
300.00	430		1.00000
1000.00	305		1.00000
3000.00	221		1.00000
[illegible] lb/sq in. abs			
1.00	2000	0.00051	0.99949
1.85	1721	.00008	.99992
3.00	1523		1.00000
10.00	1108		1.00000
30.00	818		1.00000
100.00	582		1.00000
300.00	426		1.00000
1000.00	302		1.00000
3000.00	219		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.44[illegible] lb/sq in. abs			
1.00	2000	0.00931	0.99069
1.83	1767	.00210	.99790
3.00	1572	.00040	.99961
10.00	1148		1.00000
30.00	848		1.00000
100.00	604		1.00000
300.00	442		1.00000
1000.00	313		1.00000
3000.00	228		1.00000
[illegible]			
1.00	2000	0.00162	0.99838
1.85	1727	.00026	.99974
3.00	1529	.00004	.99997
10.00	1113		1.00000
30.00	822		1.00000
100.00	585		1.00000
300.00	428		1.00000
1000.00	303		1.00000
3000.00	220		1.00000
P_c, 440.[illegible] lb/sq in. abs			
1.00	2000	0.00030	0.99970
1.85	1719	.00004	.99996
3.00	1522		1.00000
10.00	1107		1.00000
30.00	817		1.00000
100.00	582		1.00000
300.00	425		1.00000
1000.00	302		1.00000
3000.00	219		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.40[illegible] lb/sq in. abs			
1.00	2000	0.00511	0.99489
1.84	1746	.00096	.99904
3.00	1549	.00017	.99984
10.00	1129		1.00000
30.00	833		1.00000
100.00	593		1.00000
300.00	434		1.00000
1000.00	308		1.00000
3000.00	223		1.00000
[illegible]			
1.00	2000	0.00093	0.99907
1.85	1723	.00014	.99986
3.00	1526	.00002	.99999
10.00	1110		1.00000
30.00	819		1.00000
100.00	583		1.00000
300.00	427		1.00000
1000.00	302		1.00000
3000.00	219		1.00000
P_c, 140.[illegible] lb/sq in. abs			
1.00	2000	0.00016	0.99984
1.85	1719	.00002	.99998
3.00	1521		1.00000
10.00	1107		1.00000
30.00	817		1.00000
100.00	581		1.00000
300.00	425		1.00000
1000.00	302		1.00000
3000.00	219		1.00000

(f) Chamber temperature, T_c, 2200° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.148[illegible] lb/sq in. abs			
1.00	2200	0.05453	0.94547
1.75	2062	.03190	.96810
3.00	1914	.01510	.98490
10.00	1496	.00053	.99947
30.00	1121		1.00000
100.00	804		1.00000
300.00	590		1.00000
1000.00	419		1.00000
3000.00	306		1.00000
P_c, 4.40[illegible] lb/sq in. abs			
1.00	2200	0.01019	0.98981
1.83	1947	.00276	.99724
3.00	1736	.00065	.99936
10.00	1277		1.00000
30.00	947		1.00000
100.00	676		1.00000
300.00	495		1.00000
1000.00	351		1.00000
3000.00	256		1.00000
P_c, 14[illegible] lb/sq in. abs			
1.00	2200	0.00177	0.99823
1.85	1906	.00036	.99964
3.00	1691	.00007	.99994
10.00	1239		1.00000
30.00	918		1.00000
100.00	654		1.00000
300.00	479		1.00000
1000.00	340		1.00000
3000.00	248		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440[illegible] lb/sq in. abs			
1.00	2200	0.03186	0.96814
1.78	2022	.01435	.98565
3.00	1839	.00488	.99512
10.00	1380	.00007	.99993
30.00	1028		1.00000
100.00	735		1.00000
300.00	539		1.00000
1000.00	382		1.00000
3000.00	279		1.00000
P_c, 14.[illegible] lb/sq in. abs			
1.00	2200	0.00559	0.99441
1.84	1925	.00129	.99871
3.00	1712	.00028	.99973
10.00	1256		1.00000
30.00	931		1.00000
100.00	664		1.00000
300.00	485		1.00000
1000.00	345		1.00000
3000.00	251		1.00000
P_c, 44.[illegible] lb/sq in. abs			
1.00	2200	0.00107	0.99898
1.85	1992	.00020	.99980
3.00	1687	.00004	.99997
10.00	1235		1.00000
30.00	915		1.00000
100.00	653		1.00000
300.00	479		1.00000
1000.00	339		1.00000
3000.00	247		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.4[illegible] lb/sq in. abs			
1.00	2200	0.01758	0.98242
1.81	1978	.00589	.99411
3.00	1774	.00156	.99844
10.00	1311	.00001	.99999
30.00	974		1.00000
100.00	695		1.00000
300.00	509		1.00000
1000.00	362		1.00000
3000.00	264		1.00000
P_c, 14.0[illegible] lb/sq in. abs			
1.00	2200	0.00323	0.99677
1.84	1914	.00069	.99931
3.00	1699	.00015	.99986
10.00	1245		1.00000
30.00	923		1.00000
100.00	658		1.00000
300.00	482		1.00000
1000.00	342		1.00000
3000.00	249		1.00000
P_c, 140.[illegible] lb/sq in. abs			
1.00	2200	0.00056	0.99944
1.85	1990	.00011	.99989
3.00	1685	.00002	.99999
10.00	1233		1.00000
30.00	914		1.00000
100.00	651		1.00000
300.00	477		1.00000
1000.00	338		1.00000
3000.00	246		1.00000

E-692

TABLE II. - Continued. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(g) Chamber temperature, T_c, 2400° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	2400	0.14634	0.85366
1.73	2297	.11691	.88309
3.00	2192	.08857	.91143
10.00	1948	.03504	.96496
30.00	1656	.00525	.99475
100.00	1240	.00004	.99996
300.00	919		1.00000
1000.00	656		1.00000
3000.00	480		1.00000
P_c, 4.40880 lb/sq in. abs			
1.00	2400	0.02850	0.97150
1.79	2189	.01261	.98739
3.00	1981	.00448	.99552
10.00	1489	.00009	.99991
30.00	1114		1.00000
100.00	798		1.00000
300.00	585		1.00000
1000.00	416		1.00000
3000.00	304		1.00000
P_c, 146.960 lb/sq in. abs			
1.00	2400	0.00500	0.99500
1.83	2100	.00133	.99867
3.00	1870	.00034	.99967
10.00	1379		1.00000
30.00	1027		1.00000
100.00	734		1.00000
300.00	538		1.00000
1000.00	382		1.00000
3000.00	279		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	2400	0.08736	0.91264
1.74	2270	.06076	.93924
3.00	2135	.03776	.96224
10.00	1775	.00524	.99476
30.00	1370	.00010	.99991
100.00	991		1.00000
300.00	729		1.00000
1000.00	518		1.00000
3000.00	379		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	2400	0.01571	0.98429
1.81	2145	.00549	.99451
3.00	1923	.00163	.99837
10.00	1428	.00002	.99998
30.00	1065		1.00000
100.00	763		1.00000
300.00	559		1.00000
1000.00	397		1.00000
3000.00	290		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	2400	0.00289	0.99711
1.84	2090	.00072	.99928
3.00	1859	.00018	.99983
10.00	1470		1.00000
30.00	1020		1.00000
100.00	729		1.00000
300.00	534		1.00000
1000.00	379		1.00000
3000.00	277		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	2400	0.04885	0.95115
1.77	2229	.02733	.97267
3.00	2053	.01257	.98743
10.00	1590	.00049	.99951
30.00	1196		1.00000
100.00	859		1.00000
300.00	631		1.00000
1000.00	448		1.00000
3000.00	328		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	2400	0.00910	0.99090
1.83	2119	.00271	.99729
3.00	1891	.00074	.99926
10.00	1398	.00001	.99999
30.00	1042		1.00000
100.00	745		1.00000
300.00	546		1.00000
1000.00	383		1.00000
3000.00	283		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	2400	0.00158	0.99842
1.84	2084	.00038	.99962
3.00	1852	.00009	.99992
10.00	1364		1.00000
30.00	1015		1.00000
100.00	726		1.00000
300.00	532		1.00000
1000.00	377		1.00000
3000.00	275		1.00000

(h) Chamber temperature, T_c, 2600° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	2600	0.31607	0.68393
1.72	2506	.28440	.71560
3.00	2413	.25233	.74767
10.00	2226	.18515	.81485
30.00	2065	.12705	.87295
100.00	1886	.06870	.93130
300.00	1698	.02462	.97538
1000.00	1382	.00118	.99882
3000.00	1036		1.00000
P_c, 4.40880 lb/sq in. abs			
1.00	2600	0.06739	0.93261
1.76	2428	.04285	.95715
3.00	2256	.02385	.97615
10.00	1805	.00214	.99786
30.00	1376	.00003	.99998
100.00	995		1.00000
300.00	733		1.00000
1000.00	521		1.00000
3000.00	381		1.00000
P_c, 146.960 lb/sq in. abs			
1.00	2600	0.01201	0.98799
1.82	2317	.00425	.99575
3.00	2065	.00136	.99864
10.00	1539	.00003	.99997
30.00	1152		1.00000
100.00	827		1.00000
300.00	627		1.00000
1000.00	431		1.00000
3000.00	315		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	2600	0.19765	0.80235
1.72	2491	.16623	.83377
3.00	2383	.13545	.86455
10.00	2150	.07367	.92633
30.00	1915	.02771	.97229
100.00	1563	.00709	.99791
300.00	1183		1.00000
1000.00	850		1.00000
3000.00	624		1.00000
P_c, 14.6960 lb/sq in. abs			
1.00	2600	0.03750	0.96250
1.78	2382	.01917	.98083
3.00	2172	.00822	.99178
10.00	1660	.00031	.99969
30.00	1250		1.00000
100.00	900		1.00000
300.00	661		1.00000
1000.00	470		1.00000
3000.00	343		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	2600	0.00695	0.99305
1.83	2286	.00221	.99779
3.00	2041	.00067	.99933
10.00	1516	.00001	.99999
30.00	1134		1.00000
100.00	813		1.00000
300.00	596		1.00000
1000.00	424		1.00000
3000.00	305		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	2600	0.11378	0.88622
1.74	2464	.08490	.91510
3.00	2327	.05886	.94114
10.00	1991	.01512	.98488
30.00	1596	.00090	.99911
100.00	1169		1.00000
300.00	864		1.00000
1000.00	616		1.00000
3000.00	451		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	2600	0.02182	0.97818
1.80	2341	.00916	.99084
3.00	2110	.00329	.99671
10.00	1586	.00008	.99992
30.00	1189		1.00000
100.00	854		1.00000
300.00	627		1.00000
1000.00	445		1.00000
3000.00	325		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	2600	0.00381	0.99619
1.83	2275	.00113	.99887
3.00	2025	.00033	.99967
10.00	1501	.00001	.99999
30.00	1123		1.00000
100.00	805		1.00000
300.00	590		1.00000
1000.00	419		1.00000
3000.00	306		1.00000

(i) Chamber temperature, T_c, 2800° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	2800	0.54780	0.45220
1.72	2701	.51706	.48294
3.00	2606	.48575	.51425
10.00	2420	.41895	.58105
30.00	2269	.35916	.64084
100.00	2120	.29503	.70497
300.00	1996	.23796	.76204
1000.00	1868	.17733	.82267
3000.00	1755	.12428	.87572
P_c, 4.40880 lb/sq in. abs			
1.00	2800	0.13808	0.86192
1.74	2653	.10747	.89253
3.00	2510	.07934	.92066
10.00	2178	.02814	.97186
30.00	1806	.00373	.99627
100.00	1348	.00004	.99996
300.00	1003		1.00000
1000.00	717		1.00000
3000.00	525		1.00000
P_c, 146.960 lb/sq in. abs			
1.00	2800	0.02543	0.97457
1.80	2526	.01181	.98819
3.00	2283	.00481	.99519
10.00	1729	.00019	.99981
30.00	1304		1.00000
100.00	941		1.00000
300.00	692		1.00000
1000.00	492		1.00000
3000.00	360		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	2800	0.37255	0.62745
1.72	2694	.33984	.66016
3.00	2591	.30689	.69311
10.00	2387	.23723	.76277
30.00	2216	.17625	.82375
100.00	2038	.11322	.88678
300.00	1871	.06111	.93889
1000.00	1548	.01613	.98387
3000.00	1332	.00557	.99943
P_c, 14.6960 lb/sq in. abs			
1.00	2800	0.07821	0.92179
1.76	2615	.05232	.94768
3.00	2433	.03159	.96841
10.00	1976	.00434	.99566
30.00	1525	.00013	.99988
100.00	1110		1.00000
300.00	820		1.00000
1000.00	583		1.00000
3000.00	427		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	2800	0.01476	0.98524
1.81	2493	.00595	.99405
3.00	2238	.00219	.99781
10.00	1679	.00007	.99993
30.00	1264		1.00000
100.00	911		1.00000
300.00	669		1.00000
1000.00	475		1.00000
3000.00	348		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	2800	0.22656	0.77344
1.73	2677	.19378	.80622
3.00	2559	.16175	.83825
10.00	2310	.09637	.90363
30.00	2076	.04509	.95491
100.00	1759	.00780	.99220
300.00	1370	.00017	.99984
1000.00	992		1.00000
3000.00	730		1.00000
P_c, 44.0880 lb/sq in. abs			
1.00	2800	0.04594	0.95406
1.78	2572	.02584	.97416
3.00	2355	.01266	.98734
10.00	1827	.00081	.99919
30.00	1386		1.00000
100.00	1003		1.00000
300.00	738		1.00000
1000.00	525		1.00000
3000.00	384		1.00000
P_c, 1469.60 lb/sq in. ats			
1.00	2800	0.00811	0.99189
1.82	2468	.00293	.99707
3.00	2267	.00101	.99899
10.00	1649	.00003	.99997
30.00	1240		1.00000
100.00	892		1.00000
300.00	655		1.00000
1000.00	466		1.00000
3000.00	340		1.00000

TABLE II. - Continued. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(j) Chamber temperature, T_c, 3000° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	3000	0.76387	0.23613
1.73	2885	.73534	.26466
3.00	2778	.70657	.29343
10.00	2573	.64450	.35550
30.00	2412	.58857	.41143
100.00	2257	.52806	.47194
300.00	2132	.47357	.52643
1000.00	2008	.41466	.58534
3000.00	1906	.36167	.63833
P_c, 4.40880 lb/sq in. abs			
1.00	3000	0.24876	0.75124
1.73	2862	.21483	.78517
3.00	2731	.18187	.81813
10.00	2460	.11386	.88614
30.00	2215	.05929	.94071
100.00	1907	.01513	.98487
300.00	1530	.00079	.99922
1000.00	1117		1.00000
3000.00	825		1.00000
P_c, 146.960 lb/sq in. ats			
1.00	3000	0.04849	0.95151
1.78	2790	.02829	.97171
3.00	2518	.01474	.98526
10.00	1965	.00127	.99873
30.00	1499	.00003	.99998
100.00	1089		1.00000
300.00	804		1.00000
1000.00	572		1.00000
3000.00	419		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	3000	0.58480	0.41520
1.72	2886	.55316	.44684
3.00	2778	.52127	.47873
10.00	2568	.45286	.54714
30.00	2401	.39161	.60839
100.00	2237	.32588	.67412
300.00	2101	.26731	.73269
1000.00	1964	.20494	.79506
3000.00	1845	.15010	.84990
P_c, 14.6960 lb/sq in. abs			
1.00	3000	0.14533	0.85467
1.74	2834	.11396	.88604
3.00	2676	.08536	.91464
10.00	2316	.03254	.96746
30.00	1932	.00546	.99454
100.00	1456	.00010	.99990
300.00	1088		1.00000
1000.00	779		1.00000
3000.00	571		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	3000	0.02829	0.97171
1.80	2798	.01415	.98585
3.00	2452	.00635	.99365
10.00	1873	.00036	.99964
30.00	1418		1.00000
100.00	1027		1.00000
300.00	757		1.00000
1000.00	538		1.00000
3000.00	394		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	3000	0.38867	0.61133
1.73	2878	.35478	.64522
3.00	2762	.32098	.67902
10.00	2532	.24922	.75078
30.00	2342	.18643	.81357
100.00	2146	.12154	.87846
300.00	1966	.06776	.93224
1000.00	1737	.02036	.97964
3000.00	1424	.00116	.99884
P_c, 44.0880 lb/sq in. abs			
1.00	3000	0.08673	0.91327
1.76	2798	.05995	.94005
3.00	2604	.03814	.96186
10.00	2133	.00692	.99308
30.00	1665	.00033	.99968
100.00	1220		1.00000
300.00	903		1.00000
1000.00	644		1.00000
3000.00	471		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	3000	0.01560	0.98440
1.81	2672	.00681	.99319
3.00	2401	.00276	.99724
10.00	1812	.00012	.99988
30.00	1370		1.00000
100.00	991		1.00000
300.00	729		1.00000
1000.00	518		1.00000
3000.00	379		1.00000

(k) Chamber temperature, T_c, 3200° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	3200	0.89714	0.10286
1.74	3052	.87058	.12942
3.00	2923	.84416	.15584
10.00	2687	.78623	.21377
30.00	2508	.73381	.26619
100.00	2342	.67694	.32306
300.00	2209	.62558	.37442
1000.00	2081	.56989	.43011
3000.00	1976	.51960	.48040
P_c, 4.40880 lb/sq in. abs			
1.00	3200	0.39668	0.60332
1.73	3060	.36168	.63833
3.00	2930	.32714	.67286
10.00	2672	.25351	.74649
30.00	2461	.18920	.81080
100.00	2245	.12295	.87705
300.00	2049	.06832	.93168
1000.00	1801	.02062	.97938
3000.00	1476	.00130	.99870
P_c, 146.960 lb/sq in. abs			
1.00	3200	0.08463	0.91537
1.76	2970	.05838	.94162
3.00	2756	.03740	.96260
10.00	2246	.00722	.99278
30.00	1758	.00043	.99958
100.00	1292		1.00000
300.00	959		1.00000
1000.00	685		1.00000
3000.00	501		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	3200	0.77168	0.22832
1.73	3067	.74700	.25800
3.00	2946	.71238	.28762
10.00	2715	.64817	.35183
30.00	2535	.59034	.40966
100.00	2364	.52782	.47218
300.00	2226	.47158	.52842
1000.00	2091	.41084	.58916
3000.00	1979	.35628	.64372
P_c, 14.6960 lb/sq in. abs			
1.00	3200	0.24332	0.75668
1.74	3041	.20868	.79132
3.00	2892	.17549	.82451
10.00	2584	.10714	.89286
30.00	2307	.05537	.94663
100.00	1960	.01221	.98779
300.00	1556	.00058	.99943
1000.00	1136		1.00000
3000.00	839		1.00000
P_c, 440.880 lb/sq in. abs			
1.00	3200	0.04978	0.95022
1.78	2926	.02985	.97015
3.00	2678	.01629	.98371
10.00	2097	.00175	.99825
30.00	1608	.00006	.99995
100.00	1174		1.00000
300.00	868		1.00000
1000.00	618		1.00000
3000.00	453		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	3200	0.57599	0.42401
1.73	3068	.54288	.45712
3.00	2946	.50988	.49012
10.00	2709	.43883	.56117
30.00	2521	.37534	.62466
100.00	2338	.30741	.69259
300.00	2187	.24711	.75289
1000.00	2034	.18326	.81674
3000.00	1900	.12766	.87234
P_c, 44.0880 lb/sq in. ats			
1.00	3200	0.14898	0.85102
1.75	3013	.11718	.88282
3.00	2837	.08846	.91154
10.00	2445	.03504	.96496
30.00	2042	.00675	.99325
100.00	1550	.00018	.99982
300.00	1162		1.00000
1000.00	834		1.00000
3000.00	612		1.00000
P_c, 1469.60 lb/sq in. abs			
1.00	3200	0.02758	0.97242
1.80	2881	.01429	.98571
3.00	2607	.00679	.99321
10.00	1995	.00050	.99950
30.00	1519		1.00000
100.00	1105		1.00000
300.00	816		1.00000
1000.00	581		1.00000
3000.00	425		1.00000

(l) Chamber temperature, T_c, 3400° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	3400	0.95768	0.04232
1.75	3190	.93305	.06695
3.00	3032	.90856	.09144
10.00	2759	.85317	.14683
30.00	2564	.80271	.19729
100.00	2387	.74782	.25218
300.00	2249	.69819	.30181
1000.00	2116	.64432	.35568
3000.00	2008	.59563	.40437
P_c, 4.40880 lb/sq in. ats			
1.00	3400	0.56231	0.43769
1.73	3250	.52780	.47220
3.00	3113	.49377	.50623
10.00	2846	.42022	.57978
30.00	2636	.35468	.64532
100.00	2432	.28478	.71522
300.00	2265	.22305	.77695
1000.00	2094	.15820	.84180
3000.00	1943	.10257	.89743
P_c, 146.960 lb/sq in. abs			
1.00	3400	0.13678	0.86322
1.75	3183	.10568	.89432
3.00	2983	.07832	.92168
10.00	2535	.02875	.97125
30.00	2088	.00497	.99503
100.00	1576	.00013	.99987
300.00	1183		1.00000
1000.00	850		1.00000
3000.00	623		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	3400	0.89029	0.10971
1.74	3233	.86240	.13760
3.00	3090	.83494	.16506
10.00	2826	.77443	.22557
30.00	2629	.71971	.28029
100.00	2446	.66040	.33960
300.00	2301	.60688	.39312
1000.00	2161	.54891	.45109
3000.00	2047	.49663	.50337
P_c, 14.6960 lb/sq in. ats			
1.00	3400	0.36962	0.63038
1.74	3238	.33352	.66648
3.00	3090	.29839	.70161
10.00	2796	.22347	.77653
30.00	2554	.15880	.84120
100.00	2304	.09369	.90631
300.00	2068	.04293	.95708
1000.00	1744	.00690	.99310
3000.00	1354	.00014	.99986
P_c, 440.880 lb/sq in. abs			
1.00	3400	0.08146	0.91854
1.77	3141	.05608	.94392
3.00	2905	.03613	.96387
10.00	2356	.00736	.99264
30.00	1846	.00052	.99948
100.00	1362	.00001	.99999
300.00	1014		1.00000
1000.00	724		1.00000
3000.00	531		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	3400	0.74435	0.25565
1.74	3250	.71287	.28713
3.00	3115	.68178	.31822
10.00	2856	.61412	.38588
30.00	2656	.55329	.44671
100.00	2466	.48767	.51233
300.00	2314	.42976	.57124
1000.00	2165	.36537	.63467
3000.00	2042	.30856	.69144
P_c, 44.0880 lb/sq in. ats			
1.00	3400	0.23507	0.76493
1.74	3218	.19999	.80001
3.00	3050	.16688	.83312
10.00	2702	.09888	.90112
30.00	2390	.04667	.95333
100.00	2001	.00939	.99061
300.00	1574	.00041	.99960
1000.00	1149		1.00000
3000.00	849		1.00000
P_c, 1469.60 lb/sq in. ats			
1.00	3400	0.04548	0.95452
1.79	3092	.02727	.97273
3.00	2822	.01510	.98490
10.00	2204	.00181	.99819
30.00	1695	.00008	.99993
100.00	1241		1.00000
300.00	920		1.00000
1000.00	656		1.00000
3000.00	480		1.00000

E-692

TABLE II. - Continued. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(m) Chamber temperature, T_c, 3600° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	3600	0.98204	0.01796
1.77	3298	.96008	.03992
3.00	3107	.93735	.06265
10.00	2801	.88356	.11644
30.00	2595	.83410	.16590
100.00	2410	.78018	.21982
300.00	2268	.73139	.26861
1000.00	2132	.67840	.32160
3000.00	2023	.63048	.36952
P_c, 4.40880 lb/sq in. abs			
1.00	3600	0.71461	0.28539
1.74	3431	.68139	.31861
3.00	3281	.64890	.35110
10.00	2994	.57796	.42204
30.00	2772	.51431	.48569
100.00	2563	.44579	.55421
300.00	2395	.38446	.61554
1000.00	2232	.31867	.68133
3000.00	2096	.26009	.73991
P_c, 146.960 lb/sq in. abs			
1.00	3600	0.20640	0.79360
1.75	3387	.17178	.82822
3.00	3194	.13986	.86014
10.00	2789	.07546	.92454
30.00	2420	.02969	.97031
100.00	1958	.00381	.99619
300.00	1508	.00011	.99990
1000.00	1097		1.00000
3000.00	829		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	3600	0.94961	0.05039
1.75	3374	.92353	.07647
3.00	3202	.89794	.10206
10.00	2901	.83991	.16009
30.00	2687	.78709	.21291
100.00	2493	.72970	.27030
300.00	2342	.67785	.32215
1000.00	2198	.62161	.37839
3000.00	2081	.57084	.42916
P_c, 14.6960 lb/sq in. abs			
1.00	3600	0.51189	0.48811
1.74	3428	.47570	.52430
3.00	3274	.44046	.55954
10.00	2973	.36412	.63588
30.00	2735	.29652	.70348
100.00	2505	.22509	.77491
300.00	2313	.16296	.83704
1000.00	2111	.09952	.90048
3000.00	1919	.04856	.95144
P_c, 440.880 lb/sq in. abs			
1.00	3600	0.12512	0.87488
1.76	3351	.09514	.90486
3.00	3125	.06941	.93059
10.00	2623	.02396	.97604
30.00	2137	.00389	.99611
100.00	1509	.00011	.99989
300.00	1209		1.00000
1000.00	869		1.00000
3000.00	638		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	3600	0.86169	0.13831
1.74	3418	.83185	.16815
3.00	3262	.80275	.19725
10.00	2973	.73853	.26147
30.00	2756	.68056	.31944
100.00	2554	.61781	.38219
300.00	2395	.56130	.43870
1000.00	2242	.50020	.49980
3000.00	2117	.44521	.55479
P_c, 44.0880 lb/sq in. abs			
1.00	3600	0.34290	0.65710
1.74	3415	.30604	.69396
3.00	3247	.27067	.72933
10.00	2913	.19528	.80472
30.00	2698	.13117	.86883
100.00	2349	.06869	.93131
300.00	2063	.02421	.97579
1000.00	1678	.00179	.99821
3000.00	1257	.00002	.99998
P_c, 1469.60 lb/sq in. abs			
1.00	3600	0.07063	0.92937
1.76	3402	.04760	.95240
3.00	3039	.03016	.96984
10.00	2436	.00592	.99408
30.00	1904	.00044	.99956
100.00	1407	.00001	.99999
300.00	1048		1.00000
1000.00	750		1.00000
3000.00	550		1.00000

(n) Chamber temperature, T_c, 3800° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	3800	0.99187	0.00813
1.79	3383	.97336	.02664
3.00	3161	.95229	.04771
10.00	2626	.89963	.10037
30.00	2613	.85076	.14924
100.00	2424	.79738	.20262
300.00	2279	.74905	.25095
1000.00	2142	.69653	.30347
3000.00	2031	.64905	.35095
P_c, 4.40880 lb/sq in. abs			
1.00	3800	0.82943	0.17057
1.75	3601	.79765	.20235
3.00	3432	.76696	.23304
10.00	3115	.69908	.30092
30.00	2877	.63793	.36207
100.00	2656	.57185	.42815
300.00	2483	.51245	.48755
1000.00	2316	.44838	.55162
3000.00	2180	.39087	.60913
P_c, 146.960 lb/sq in. abs			
1.00	3800	0.29257	0.70743
1.75	3584	.25562	.74438
3.00	3392	.22086	.77914
10.00	3005	.14733	.85267
30.00	2681	.08711	.91289
100.00	2323	.03377	.96623
300.00	1942	.00590	.99410
1000.00	1467	.00012	.99988
3000.00	1096		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	3800	0.97636	0.02364
1.77	3487	.95273	.04727
3.00	3283	.92886	.07114
10.00	2948	.87250	.12750
30.00	2721	.82076	.17924
100.00	2520	.76440	.23560
300.00	2364	.71344	.28656
1000.00	2217	.65814	.34186
3000.00	2098	.60818	.39182
P_c, 14.6960 lb/sq in. abs			
1.00	3800	0.65039	0.34961
1.74	3611	.61497	.38503
3.00	3446	.58071	.41929
10.00	3125	.50570	.49430
30.00	2879	.43865	.56135
100.00	2647	.36682	.63318
300.00	2460	.30295	.69705
1000.00	2276	.23509	.76491
3000.00	2121	.17552	.82448
P_c, 440.880 lb/sq in. abs			
1.00	3800	0.18167	0.81833
1.76	3554	.14806	.85194
3.00	3335	.11782	.88218
10.00	2870	.05806	.94194
30.00	2443	.01921	.98079
100.00	1925	.00177	.99823
300.00	1472	.00004	.99997
1000.00	1069		1.00000
3000.00	788		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	3800	0.92872	0.07128
1.76	3566	.90050	.09950
3.00	3384	.87321	.12679
10.00	3058	.81157	.18843
30.00	2823	.75562	.24438
100.00	2610	.69491	.30509
300.00	2444	.64015	.35985
1000.00	2286	.58085	.41915
3000.00	2159	.52738	.47262
P_c, 44.0880 lb/sq in. abs			
1.00	3800	0.46466	0.53534
1.74	3625	.42720	.57280
3.00	3431	.39116	.60884
10.00	3092	.31299	.68701
30.00	2825	.24432	.75568
100.00	2564	.17274	.82726
300.00	2341	.11204	.88796
1000.00	2095	.05353	.94647
3000.00	1830	.01435	.98565
P_c, 1469.60 lb/sq in. abs			
1.00	3800	0.10411	0.89589
1.77	3509	.07673	.92327
3.00	3252	.05418	.94582
10.00	2680	.01643	.98357
30.00	2149	.00229	.99771
100.00	1610	.00006	.99994
300.00	1209		1.00000
1000.00	869		1.00000
3000.00	638		1.00000

(o) Chamber temperature, T_c, 4000° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	4000	0.99606	0.00394
1.80	3457	.98123	.01877
3.00	3206	.96183	.03817
10.00	2848	.91015	.08985
30.00	2625	.86170	.13830
100.00	2433	.80868	.19132
300.00	2286	.76065	.23935
1000.00	2148	.70846	.29154
3000.00	2037	.66126	.33874
P_c, 4.40880 lb/sq in. abs			
1.00	4000	0.90283	0.09717
1.76	3756	.87252	.12747
3.00	3562	.84355	.15645
10.00	3209	.77825	.22175
30.00	2953	.71913	.28087
100.00	2721	.65510	.34490
300.00	2540	.59742	.40258
1000.00	2368	.53507	.46493
3000.00	2230	.47895	.52105
P_c, 146.960 lb/sq in. abs			
1.00	4000	0.39137	0.60863
1.75	3776	.35311	.64689
3.00	3579	.31688	.68312
10.00	3191	.23848	.76152
30.00	2883	.17089	.82911
100.00	2574	.10299	.89701
300.00	2294	.04998	.95002
1000.00	1940	.01055	.98945
3000.00	1531	.00044	.99956

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	4000	0.98836	0.01164
1.79	3579	.96786	.03214
3.00	3344	.94565	.05435
10.00	2979	.89051	.10949
30.00	2742	.83943	.16057
100.00	2535	.78367	.21633
300.00	2377	.73322	.26678
1000.00	2228	.67846	.32154
3000.00	2108	.62897	.37103
P_c, 14.6960 lb/sq in. abs			
1.00	4000	0.76653	0.23347
1.75	3795	.73225	.26775
3.00	3602	.69944	.30056
10.00	3256	.62684	.37316
30.00	2995	.56162	.43838
100.00	2753	.49139	.50861
300.00	2562	.42849	.57151
1000.00	2378	.36096	.63904
3000.00	2228	.30073	.69927
P_c, 440.880 lb/sq in. abs			
1.00	4000	0.25071	0.74929
1.76	3751	.21441	.78559
3.00	3533	.18095	.81905
10.00	3087	.11103	.88897
30.00	2708	.05671	.94329
100.00	2274	.01524	.98476
300.00	1821	.00134	.99866
1000.00	1347	.00001	.99999
3000.00	1002		1.00000

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	4000	0.96314	0.03686
1.77	3691	.93697	.06303
3.00	3478	.91138	.08862
10.00	3115	.85158	.14842
30.00	2866	.79689	.20311
100.00	2644	.73742	.26258
300.00	2473	.68372	.31628
1000.00	2311	.62550	.37450
3000.00	2182	.57298	.42702
P_c, 44.0880 lb/sq in. abs			
1.00	4000	0.58793	0.41207
1.75	3789	.55070	.44930
3.00	3604	.51506	.48494
10.00	3249	.43689	.56311
30.00	2976	.36733	.63267
100.00	2718	.29333	.70667
300.00	2558	.22822	.77178
1000.00	2299	.16021	.83979
3000.00	2116	.10235	.89765
P_c, 1469.60 lb/sq in. abs			
1.00	4000	0.14655	0.85345
1.77	3711	.11546	.88454
3.00	3459	.08847	.91153
10.00	2917	.03748	.96252
30.00	2419	.00944	.99056
100.00	1860	.00058	.99942
300.00	1411		1.00000
1000.00	1022		1.00000
3000.00	753		1.00000

TABLE II. - Continued. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(p) Chamber temperature, T_c, 4200° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	4200	0.99796	0.00204
1.83	3531	.98650	.01340
3.00	3248	.96903	.03097
10.00	2864	.91829	.08171
30.00	2636	.87018	.12982
100.00	2440	.81746	.18254
300.00	2292	.76967	.23033
1000.00	2153	.71773	.28227
3000.00	2041	.67075	.32925
P_c, 4.40880 lb/sq in. abs			
1.00	4200	0.94514	0.05486
1.77	3891	.91657	.08343
3.00	3668	.88923	.11077
10.00	3277	.82591	.17409
30.00	3005	.76821	.23179
100.00	2762	.70557	.29443
300.00	2576	.64908	.35092
1000.00	2400	.58784	.41206
3000.00	2260	.53285	.46715
P_c, 146.960 lb/sq in. abs			
1.00	4200	0.49613	0.50387
1.75	3962	.45738	.54262
3.00	3756	.42072	.57928
10.00	3357	.34032	.65968
30.00	3049	.26951	.73049
100.00	2753	.19548	.80452
300.00	2508	.13226	.86774
1000.00	2247	.07015	.92985
3000.00	1986	.02514	.97486

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	4200	0.99393	0.00607
1.80	3659	.97692	.02308
3.00	3393	.95635	.04365
10.00	3002	.90225	.09775
30.00	2757	.85163	.14837
100.00	2546	.79628	.20372
300.00	2386	.74618	.25382
1000.00	2235	.69177	.30823
3000.00	2115	.64259	.35741
P_c, 14.6960 lb/sq in. abs			
1.00	4200	0.85156	0.14844
1.76	3949	.81854	.18146
3.00	3744	.78729	.21271
10.00	3364	.71715	.28285
30.00	3085	.65389	.34611
100.00	2832	.58556	.41444
300.00	2634	.52417	.47583
1000.00	2446	.45801	.54199
3000.00	2295	.39868	.60132
P_c, 440.880 lb/sq in. abs			
1.00	4200	0.33024	0.66976
1.76	3943	.29212	.70788
3.00	3721	.25659	.74341
10.00	3279	.18015	.81985
30.00	2923	.11611	.88389
100.00	2553	.05589	.94411
300.00	2192	.01682	.98318
1000.00	1721	.00103	.99897
3000.00	1303	.00001	.99999

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	4200	0.98033	0.01967
1.79	3795	.95683	.04317
3.00	3550	.93287	.06713
10.00	3154	.87447	.12553
30.00	2893	.82059	.17941
100.00	2664	.76187	.23813
300.00	2490	.70880	.29120
1000.00	2326	.65125	.34875
3000.00	2195	.59930	.40070
P_c, 44.0880 lb/sq in. abs			
1.00	4200	0.69951	0.30049
1.75	3966	.66301	.33699
3.00	3767	.62839	.37161
10.00	3387	.55167	.44833
30.00	3101	.48299	.51701
100.00	2836	.40933	.59067
300.00	2626	.34373	.65627
1000.00	2422	.27385	.72615
3000.00	2254	.21224	.78776
P_c, 1469.60 lb/sq in. abs			
1.00	4200	0.19794	0.80206
1.76	3909	.16384	.83616
3.00	3657	.13330	.86670
10.00	3135	.07130	.92870
30.00	2680	.02828	.97172
100.00	2152	.00423	.99577
300.00	1666	.00018	.99983
1000.00	1219		1.00000
3000.00	903		1.00000

(q) Chamber temperature, T_c, 4400° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	4400	0.99888	0.00112
1.86	3608	.99049	.00951
3.00	3291	.97496	.02504
10.00	2880	.92524	.07476
30.00	2645	.87746	.12254
100.00	2447	.82499	.17501
300.00	2298	.77741	.22259
1000.00	2157	.72569	.27431
3000.00	2045	.67890	.32110
P_c, 4.40880 lb/sq in. abs			
1.00	4400	0.96850	0.03150
1.78	4007	.94215	.05785
3.00	3752	.91642	.08358
10.00	3326	.85464	.14536
30.00	3040	.79791	.20209
100.00	2790	.73618	.26382
300.00	2599	.68045	.31955
1000.00	2420	.62010	.37990
3000.00	2278	.56569	.43431
P_c, 146.960 lb/sq in. abs			
1.00	4400	0.59871	0.40129
1.76	4142	.56006	.43994
3.00	3924	.52371	.47629
10.00	3505	.44316	.55684
30.00	3188	.37151	.62849
100.00	2892	.29538	.70462
300.00	2655	.22854	.77146
1000.00	2419	.15898	.84102
3000.00	2215	.10018	.89982

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	4400	0.99666	0.00334
1.82	3735	.98307	.01693
3.00	3438	.96423	.03577
10.00	3021	.91111	.08889
30.00	2769	.86087	.13913
100.00	2555	.80585	.19415
300.00	2393	.75600	.24400
1000.00	2241	.70156	.29844
3000.00	2120	.65293	.34707
P_c, 14.6960 lb/sq in. abs			
1.00	4400	0.90775	0.09225
1.77	4097	.87613	.12387
3.00	3866	.84642	.15358
10.00	3449	.77840	.22160
30.00	3153	.71674	.28326
100.00	2888	.64999	.35001
300.00	2684	.58991	.41009
1000.00	2491	.52503	.47497
3000.00	2338	.46673	.53327
P_c, 440.880 lb/sq in. abs			
1.00	4400	0.41674	0.58326
1.76	4130	.37750	.62250
3.00	3900	.34086	.65914
10.00	3451	.26062	.73938
30.00	3101	.19109	.80891
100.00	2759	.12064	.87936
300.00	2461	.06440	.93560
1000.00	2107	.01858	.98142
3000.00	1706	.00154	.99846

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	4400	0.98905	0.01095
1.80	3884	.96868	.03132
3.00	3608	.94633	.05367
10.00	3183	.88908	.11092
30.00	2912	.83577	.16423
100.00	2679	.77755	.22245
300.00	2502	.72490	.27510
1000.00	2336	.66778	.33222
3000.00	2204	.61621	.38379
P_c, 44.0880 lb/sq in. abs			
1.00	4400	0.79026	0.20974
1.76	4134	.75475	.24525
3.00	3916	.72142	.27858
10.00	3506	.64670	.35330
30.00	3204	.57954	.42046
100.00	2928	.50721	.49279
300.00	2712	.44248	.55752
1000.00	2507	.37302	.62698
3000.00	2341	.31112	.68888
P_c, 1469.60 lb/sq in. abs			
1.00	4400	0.25753	0.74247
1.76	4129	.22109	.77891
3.00	3847	.18789	.81211
10.00	3334	.11760	.88240
30.00	2909	.06253	.93747
100.00	2442	.01912	.98088
300.00	1973	.00232	.99768
1000.00	1471	.00004	.99996
3000.00	1099		1.00000

(r) Chamber temperature, T_c, 4600° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	4600	0.99936	0.00064
1.85	3691	.99335	.00665
3.00	3339	.98006	.01994
10.00	2895	.93149	.06851
30.00	2654	.88401	.11599
100.00	2453	.83179	.16821
300.00	2302	.78440	.21560
1000.00	2161	.73287	.26713
3000.00	2048	.68626	.31374
P_c, 4.40880 lb/sq in. abs			
1.00	4600	0.98137	0.01863
1.80	4107	.95773	.04227
3.00	3821	.93358	.06642
10.00	3362	.87308	.12692
30.00	3065	.81703	.18297
100.00	2808	.75592	.24408
300.00	2614	.70070	.29930
1000.00	2433	.64087	.35913
3000.00	2290	.58692	.41308
P_c, 146.960 lb/sq in. abs			
1.00	4600	0.69156	0.30844
1.76	4316	.65340	.34660
3.00	4082	.61783	.38217
10.00	3637	.53820	.46180
30.00	3306	.46698	.53302
100.00	3002	.39074	.60926
300.00	2764	.32306	.67694
1000.00	2534	.25127	.74873
3000.00	2344	.18844	.81156

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	4600	0.99807	0.00193
1.85	3813	.98756	.01244
3.00	3484	.97061	.02939
10.00	3038	.91851	.08149
30.00	2780	.86861	.13139
100.00	2562	.81386	.18614
300.00	2399	.76424	.23576
1000.00	2246	.71033	.28967
3000.00	2124	.66160	.33840
P_c, 14.6960 lb/sq in. abs			
1.00	4600	0.94269	0.05731
1.78	4230	.91277	.08723
3.00	3969	.88458	.11542
10.00	3514	.81831	.18169
30.00	3202	.75785	.24215
100.00	2927	.69225	.30775
300.00	2717	.63314	.36686
1000.00	2521	.56923	.43077
3000.00	2365	.51173	.48827
P_c, 440.880 lb/sq in. abs			
1.00	4600	0.50554	.49446
1.76	4313	.46577	.53423
3.00	4072	.42874	.57126
10.00	3606	.34666	.65334
30.00	3253	.27435	.72565
100.00	2919	.19881	.80119
300.00	2645	.13446	.86554
1000.00	2357	.07151	.92849
3000.00	2075	.02614	.97386

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	4600	0.99363	0.00637
1.82	3966	.97654	.02346
3.00	3659	.95584	.04416
10.00	3206	.89963	.10037
30.00	2927	.84676	.15324
100.00	2689	.78892	.21108
300.00	2510	.73657	.26343
1000.00	2343	.67978	.32022
3000.00	2211	.62849	.37151
P_c, 44.0880 lb/sq in. abs			
1.00	4600	0.85768	0.14232
1.77	4293	.82330	.17670
3.00	4051	.79134	.20866
10.00	3606	.71863	.28137
30.00	3286	.65302	.34698
100.00	2998	.58217	.41783
300.00	2776	.51859	.48141
1000.00	2566	.45014	.54986
3000.00	2399	.38886	.61114
P_c, 1469.60 lb/sq in. abs			
1.00	4600	0.32380	0.67620
1.76	4291	.28562	.71438
3.00	4030	.25055	.74945
10.00	3514	.17439	.82561
30.00	3105	.11094	.88906
100.00	2686	.05215	.94785
300.00	2284	.01528	.98472
1000.00	1785	.00099	.99901
3000.00	1353	.00001	.99999

E-692

CT-6

TABLE II. - Concluded. EQUILIBRIUM COMPOSITION OF HYDROGEN AS A ROCKET PROPELLANT

[Isentropic expansion from chamber conditions.]

(s) Chamber temperature, T_c, 4800° K

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	4800	0.99961	0.00039
1.92	3782	.99544	.00456
3.00	3392	.98447	.01553
10.00	2910	.93724	.06276
30.00	2663	.89008	.10992
100.00	2459	.83808	.16192
300.00	2307	.79087	.20913
1000.00	2165	.73953	.26047
3000.00	2052	.69308	.30692
P_c, 4.40880 lb/sq in. abs			
1.00	4800	0.98860	0.01140
1.81	4197	.96797	.03203
3.00	3880	.94540	.05460
10.00	3390	.88603	.11397
30.00	3083	.83050	.16950
100.00	2822	.76984	.23016
300.00	2625	.71499	.28501
1000.00	2443	.65555	.34445
3000.00	2298	.60192	.39808
P_c, 146.960 lb/sq in. abs			
1.00	4800	0.76964	0.23036
1.77	4483	.73222	.26778
3.00	4230	.69768	.30232
10.00	3753	.61950	.38050
30.00	3406	.54930	.45070
100.00	3092	.47384	.52616
300.00	2848	.40647	.59353
1000.00	2617	.33447	.66553
3000.00	2431	.27064	.72936

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	4800	0.99884	0.00116
1.88	3895	.99092	.00908
3.00	3531	.97604	.02396
10.00	3054	.92505	.07495
30.00	2789	.87548	.12452
100.00	2569	.82098	.17902
300.00	2404	.77156	.22844
1000.00	2250	.71786	.28214
3000.00	2128	.66931	.33069
P_c, 14.6960 lb/sq in. abs			
1.00	4800	0.96387	0.03613
1.79	4346	.93606	.06394
3.00	4055	.90940	.09060
10.00	3564	.84459	.15541
30.00	3237	.78502	.21498
100.00	2954	.72024	.27976
300.00	2740	.66180	.33820
1000.00	2541	.59859	.40141
3000.00	2383	.54168	.45832
P_c, 440.880 lb/sq in. abs			
1.00	4800	0.59163	0.40837
1.77	4491	.55178	.44822
3.00	4236	.51491	.48509
10.00	3748	.43234	.56766
30.00	3384	.35895	.64105
100.00	3048	.28118	.71882
300.00	2780	.21323	.78677
1000.00	2515	.14312	.85688
3000.00	2284	.08491	.91509

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	4800	0.99614	0.00386
1.84	4046	.98222	.01778
3.00	3708	.96324	.03676
10.00	3225	.90805	.09195
30.00	2939	.85556	.14444
100.00	2698	.79803	.20197
300.00	2517	.74594	.25406
1000.00	2349	.68940	.31060
3000.00	2216	.63834	.36166
P_c, 44.0880 lb/sq in. abs			
1.00	4800	0.90454	0.09546
1.78	4438	.87149	.12851
3.00	4170	.84094	.15906
10.00	3687	.77095	.22995
30.00	3349	.70576	.29424
100.00	3050	.63618	.36382
300.00	2822	.57363	.42637
1000.00	2608	.50617	.49383
3000.00	2438	.44565	.55435
P_c, 1469.60 lb/sq in. abs			
1.00	4800	0.39457	0.60543
1.77	4476	.35516	.64484
3.00	4206	.31890	.68110
10.00	3679	.23881	.76119
30.00	3274	.16989	.83011
100.00	2879	.10125	.89875
300.00	2532	.04868	.95132
1000.00	2116	.01076	.98924
3000.00	1672	.00061	.99939

(t) Chamber temperature, T_c, 5000° K

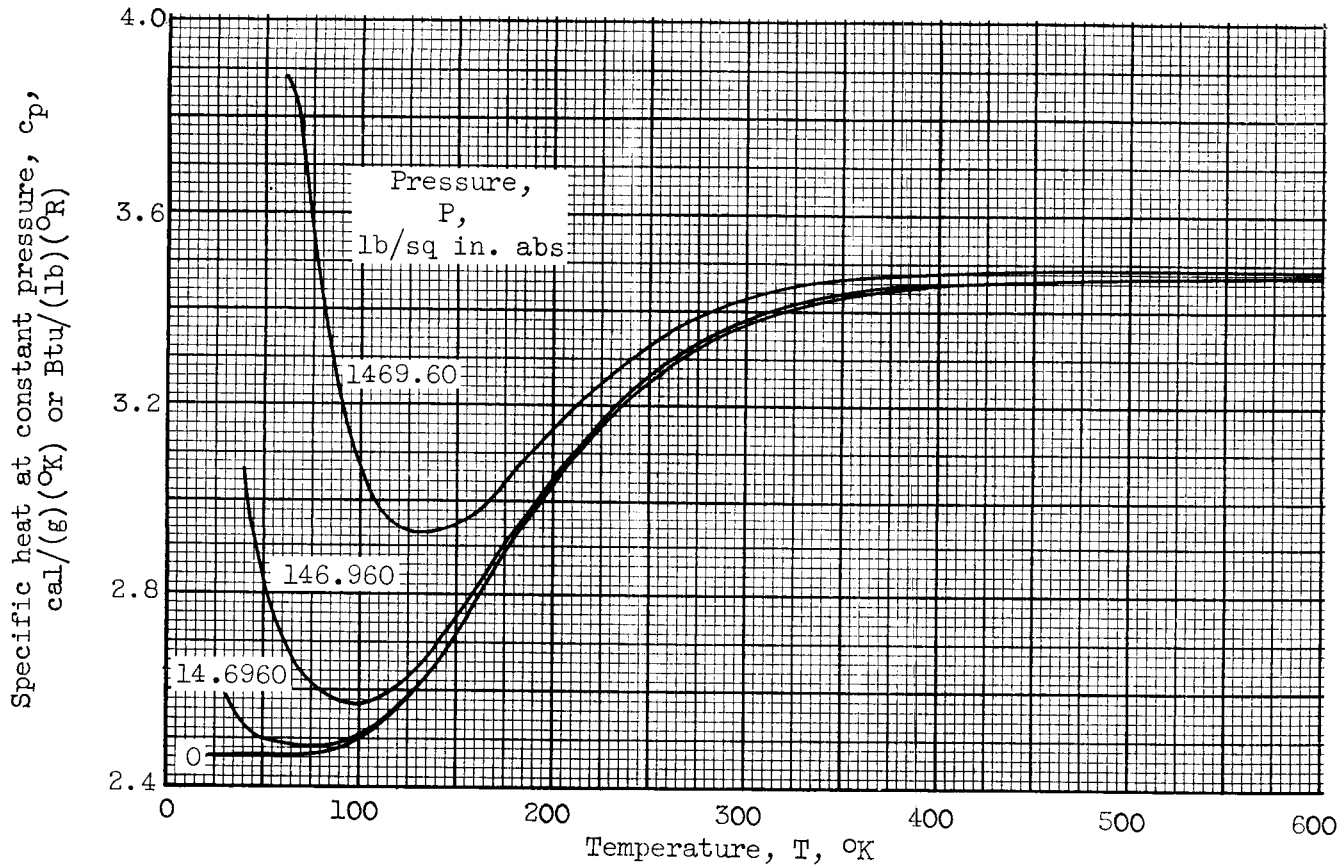
Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.146960 lb/sq in. abs			
1.00	5000	0.99976	0.00024
1.96	3882	.99692	.00308
3.00	3452	.98825	.01175
10.00	2926	.94262	.05738
30.00	2671	.89578	.10422
100.00	2464	.84399	.15601
300.00	2311	.79695	.20305
1000.00	2168	.74579	.25421
3000.00	2055	.69948	.30052
P_c, 4.40880 lb/sq in. abs			
1.00	5000	0.99278	0.00722
1.83	4282	.97523	.02477
3.00	3934	.95428	.04572
10.00	3414	.89597	.10403
30.00	3099	.84087	.15913
100.00	2833	.78057	.21943
300.00	2634	.72602	.27398
1000.00	2450	.66688	.33312
3000.00	2305	.61351	.38649
P_c, 146.960 lb/sq in. abs			
1.00	5000	0.83129	0.16871
1.78	4642	.79479	.20521
3.00	4366	.76141	.23859
10.00	3854	.68485	.31515
30.00	3489	.61582	.38418
100.00	3163	.54142	.45858
300.00	2914	.47481	.52519
1000.00	2679	.40331	.59669
3000.00	2492	.33957	.66043

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 0.440880 lb/sq in. abs			
1.00	5000	0.99927	0.00073
1.91	3983	.99346	.00654
3.00	3583	.98075	.01925
10.00	3070	.93102	.06898
30.00	2799	.88177	.11823
100.00	2575	.82751	.17249
300.00	2409	.77827	.22173
1000.00	2254	.72477	.27523
3000.00	2131	.67638	.32362
P_c, 14.6960 lb/sq in. abs			
1.00	5000	0.97671	0.02329
1.81	4450	.95140	.04860
3.00	4128	.92626	.07374
10.00	3602	.86273	.13727
30.00	3254	.80383	.19617
100.00	2974	.73964	.26036
300.00	2757	.68170	.31830
1000.00	2555	.61899	.38101
3000.00	2396	.56250	.43750
P_c, 440.880 lb/sq in. abs			
1.00	5000	0.67062	0.32938
1.77	4693	.63101	.36899
3.00	4392	.59467	.40533
10.00	3877	.51251	.48749
30.00	3499	.43906	.56094
100.00	3155	.36065	.63935
300.00	2886	.29132	.70868
1000.00	2628	.21832	.78168
3000.00	2413	.15517	.84483

Pressure ratio, P_c/P	Temperature, T, °K	Mole fraction H	Mole fraction H_2
P_c, 1.46960 lb/sq in. abs			
1.00	5000	0.99757	0.00243
1.86	4128	.98650	.01350
3.00	3757	.96938	.03062
10.00	3244	.91526	.08474
30.00	2951	.86312	.13688
100.00	2706	.80587	.19413
300.00	2574	.75400	.24600
1000.00	2354	.69769	.30231
3000.00	2220	.64682	.35318
P_c, 44.0880 lb/sq in. abs			
1.00	5000	0.93585	0.06415
1.79	4571	.90440	.09560
3.00	4274	.87528	.12472
10.00	3752	.80599	.19401
30.00	3398	.74275	.25725
100.00	3088	.67417	.32583
300.00	2855	.61244	.38756
1000.00	2637	.54579	.45421
3000.00	2465	.48592	.51408
P_c, 1469.60 lb/sq in. abs			
1.00	5000	0.46717	0.53283
1.77	4657	.42697	.57303
3.00	4375	.39008	.60992
10.00	3832	.30756	.69244
30.00	3422	.23526	.76474
100.00	3036	.16072	.83928
300.00	2716	.09894	.90106
1000.00	2370	.04245	.95755
3000.00	2010	.00945	.99055

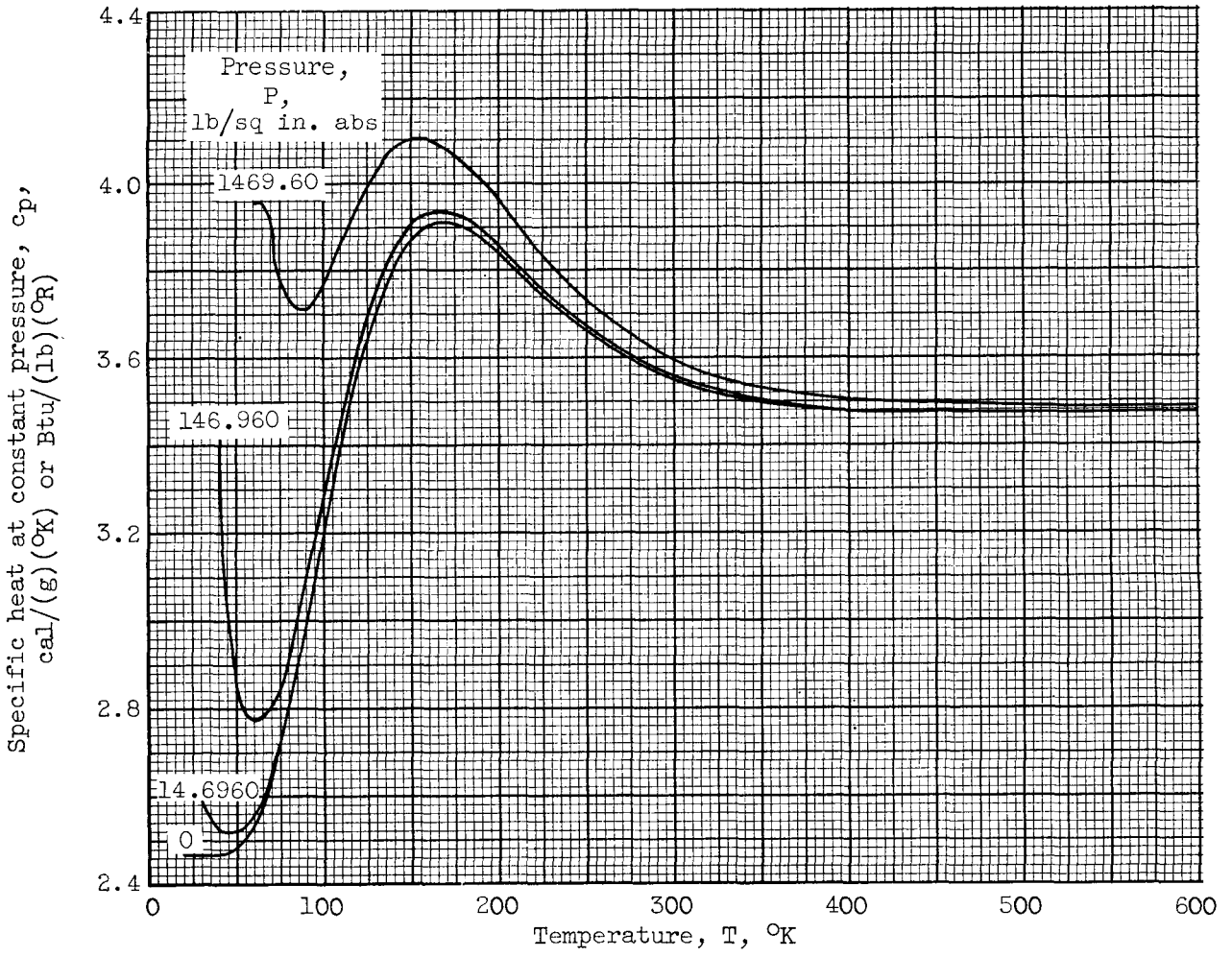
TABLE III. - CHARACTERISTIC VELOCITY AND ENTROPY OF HYDROGEN AS A ROCKET PROPELLANT

Chamber temperature, T_c, °K	Characteristic velocity, c^*, ft/sec	Entropy, S, cal/(g)(°K)	Chamber temperature, T_c, °K	Characteristic velocity, c^*, ft/sec	Entropy, S, cal/(g)(°K)	Chamber temperature, T_c, °K	Characteristic velocity, c^*, ft/sec	Entropy, S, cal/(g)(°K)
P_c, 0.146960 lb/sq in. abs			P_c, 0.440880 lb/sq in. abs			P_c, 1.46960 lb/sq in. abs		
600	7543	22.4372	600	7543	21.3543	600	7543	20.1675
800	8719	23.4415	800	8719	22.3586	800	8719	21.1719
1000	9767	24.2323	1000	9767	23.1494	1000	9767	21.9627
1200	10729	24.8931	1200	10729	23.8102	1200	10729	22.6234
1400	11628	25.4681	1400	11627	24.3848	1400	11626	23.1978
1600	12487	25.9879	1600	12479	24.9009	1600	12474	23.7117
1800	13377	26.4974	1800	13329	25.3906	1800	13299	24.1891
2000	14437	27.0991	2000	14275	25.9164	2000	14163	24.6686
2200	15651	27.9984	2200	15386	26.6016	2200	15145	25.2209
2400	16933	29.5552	2400	16559	27.6563	2400	16228	25.9634
2600	18544	32.2499	2600	17867	29.3815	2600	17361	27.0672
2800	20703	36.3860	2800	19535	32.1004	2800	18657	28.7428
3000	23148	41.2254	3000	21649	35.8682	3000	20268	31.1760
3200	25150	44.9830	3200	23912	39.9547	3200	22229	34.3410
3400	26384	47.0292	3400	25773	43.1332	3400	24317	37.7443
3600	27070	48.0204	3600	27000	45.0082	3600	26140	40.5893
3800	27477	48.5813	3800	27739	46.0130	3800	27468	42.4842
4000	27767	48.9508	4000	28202	46.5921	4000	28346	43.6098
4200	28024	49.2420	4200	28533	46.9796	4200	28925	44.2863
4400	28292	49.4948	4400	28817	47.2781	4400	29334	44.7321
4600	28599	49.7255	4600	29085	47.5315	4600	29659	45.0615
4800	28955	49.9412	4800	29378	47.7591	4800	29951	45.3294
5000	29362	50.1456	5000	29708	47.9701	5000	30239	45.5626
P_c, 4.40880 lb/sq in. abs			P_c, 14.6960 lb/sq in. abs			P_c, 44.0880 lb/sq in. abs		
600	7543	19.0846	600	7543	17.8979	600	7543	16.8150
800	8719	20.0890	800	8719	18.9022	800	8719	17.8193
1000	9767	20.8798	1000	9767	19.6930	1000	9767	18.6101
1200	10729	21.5405	1200	10729	20.3537	1200	10729	19.2708
1400	11626	22.1148	1400	11626	20.9279	1400	11626	19.8450
1600	12472	22.6275	1600	12470	21.4399	1600	12469	20.3566
1800	13284	23.0986	1800	13274	21.9072	1800	13270	20.8219
2000	14102	23.5545	2000	14064	22.3484	2000	14044	21.2557
2200	14988	24.0387	2200	14879	22.7906	2200	14819	21.6763
2400	15974	24.6212	2400	15760	23.2741	2400	15627	22.1091
2600	17015	25.4029	2600	16708	23.8562	2600	16489	22.5889
2800	18120	26.5126	2800	17696	24.6098	2800	17395	23.1592
3000	19392	28.0890	3000	18748	25.6184	3000	18334	23.8704
3200	20930	30.2311	3200	19938	26.9635	3200	19333	24.7750
3400	22742	32.8881	3400	21332	28.6978	3400	20444	25.9203
3600	24670	35.7347	3600	22940	30.7948	3600	21709	27.3342
3800	26436	38.2566	3800	24681	33.0921	3800	23140	29.0027
4000	27833	40.1165	4000	26386	35.3013	4000	24698	30.8442
4200	28839	41.3366	4200	27879	37.1474	4200	26287	32.7056
4400	29541	42.1151	4400	29071	38.5215	4400	27782	34.4063
4600	30047	42.6338	4600	29972	39.4803	4600	29085	35.8168
4800	30437	43.0082	4800	30646	40.1432	4800	30154	36.9035
5000	30767	43.3017	5000	31162	40.6169	5000	31003	37.7086
P_c, 146.960 lb/sq in. abs			P_c, 440.880 lb/sq in. abs			P_c, 1469.60 lb/sq in. abs		
600	7543	15.6282	600	7543	14.5453	600	7543	13.3585
800	8719	16.6325	800	8719	15.5496	800	8719	14.3629
1000	9767	17.4233	1000	9767	16.3404	1000	9767	15.1537
1200	10729	18.0841	1200	10729	17.0011	1200	10729	15.8144
1400	11626	18.6582	1400	11626	17.5753	1400	11626	16.3885
1600	12469	19.1696	1600	12469	18.0866	1600	12468	16.8997
1800	13267	19.6336	1800	13265	18.5500	1800	13264	17.3627
2000	14032	20.0628	2000	14026	18.9768	2000	14022	17.7881
2200	14782	20.4701	2200	14762	19.3773	2200	14750	18.1844
2400	15537	20.8717	2400	15489	19.7628	2400	15459	18.5600
2600	16321	21.2882	2600	16224	20.1470	2600	16160	18.9242
2800	17142	21.7451	2800	16979	20.5457	2800	16865	19.2870
3000	17992	22.2711	3000	17758	20.9769	3000	17581	19.6595
3200	18869	22.8971	3200	18558	21.4591	3200	18311	20.0527
3400	19793	23.6530	3400	19380	22.0111	3400	19053	20.4779
3600	20793	24.5644	3600	20235	22.6500	3600	19811	20.9455
3800	21899	25.6467	3800	21144	23.3895	3800	20589	21.4643
4000	23126	26.8979	4000	22124	24.2382	4000	21398	22.0414
4200	24465	28.2885	4200	23190	25.1966	4200	22251	22.6817
4400	25875	29.7555	4400	24342	26.2537	4400	23156	23.3865
4600	27293	31.2085	4600	25567	27.3842	4600	24119	24.1531
4800	28641	32.5521	4800	26834	28.5481	4800	25140	24.9736
5000	29857	33.7162	5000	28104	29.6952	5000	26210	25.8346



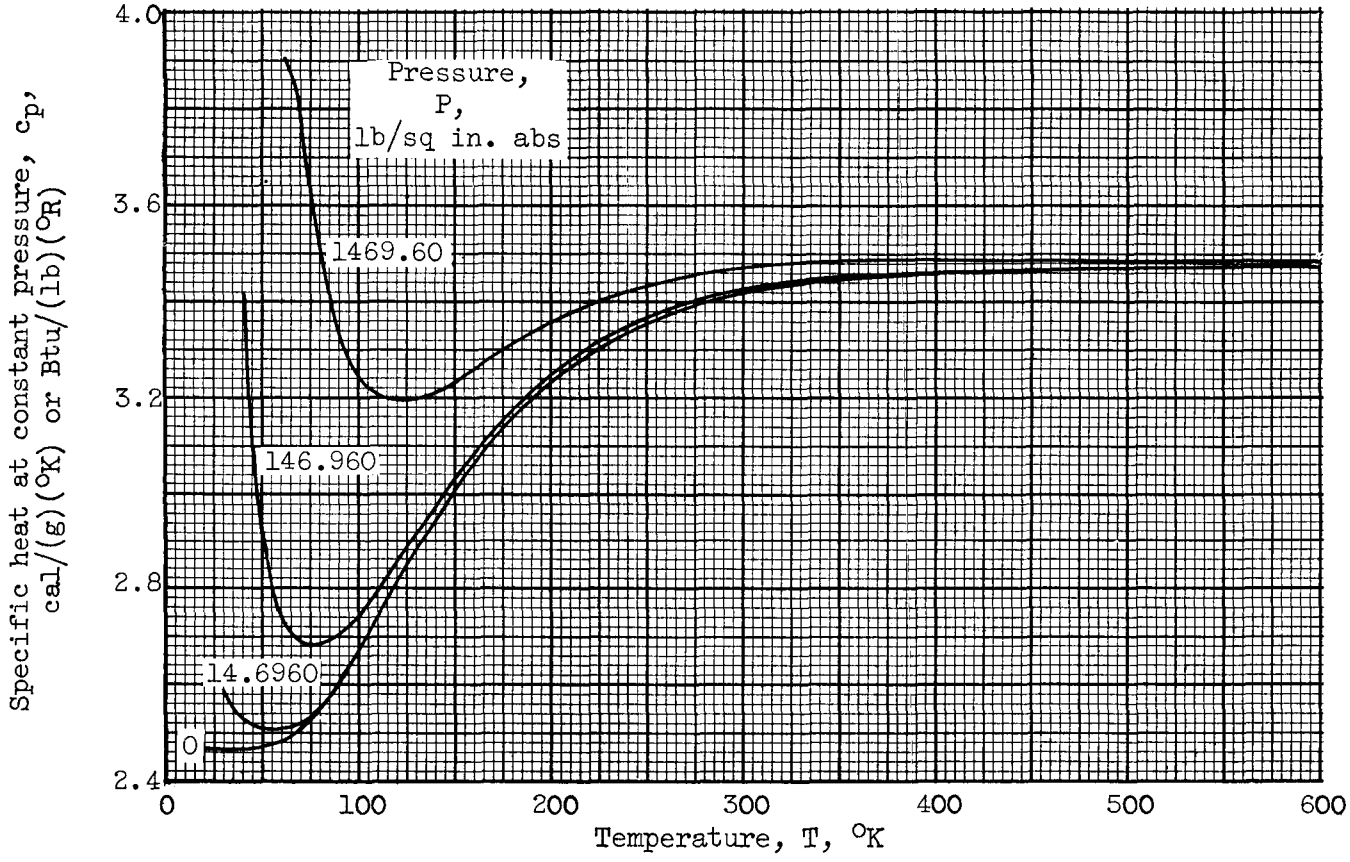
(a) Orthohydrogen.

Figure 1. - Specific heat at constant pressure of gaseous hydrogen for temperatures from 0° to 600° K.



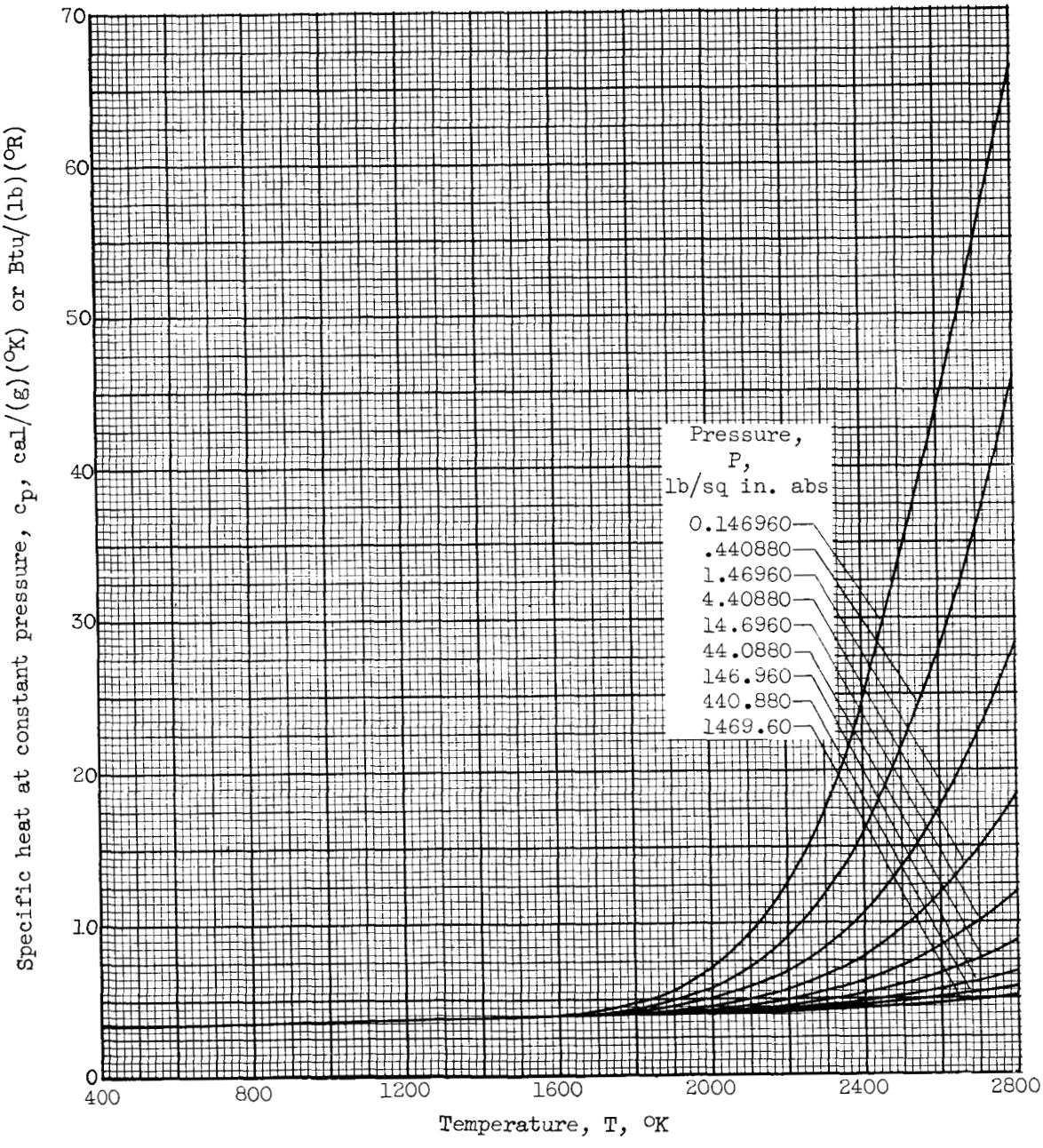
(b) Parahydrogen.

Figure 1. - Continued. Specific heat at constant pressure of gaseous hydrogen for temperatures from 0° to 600° K.



(c) Normal hydrogen.

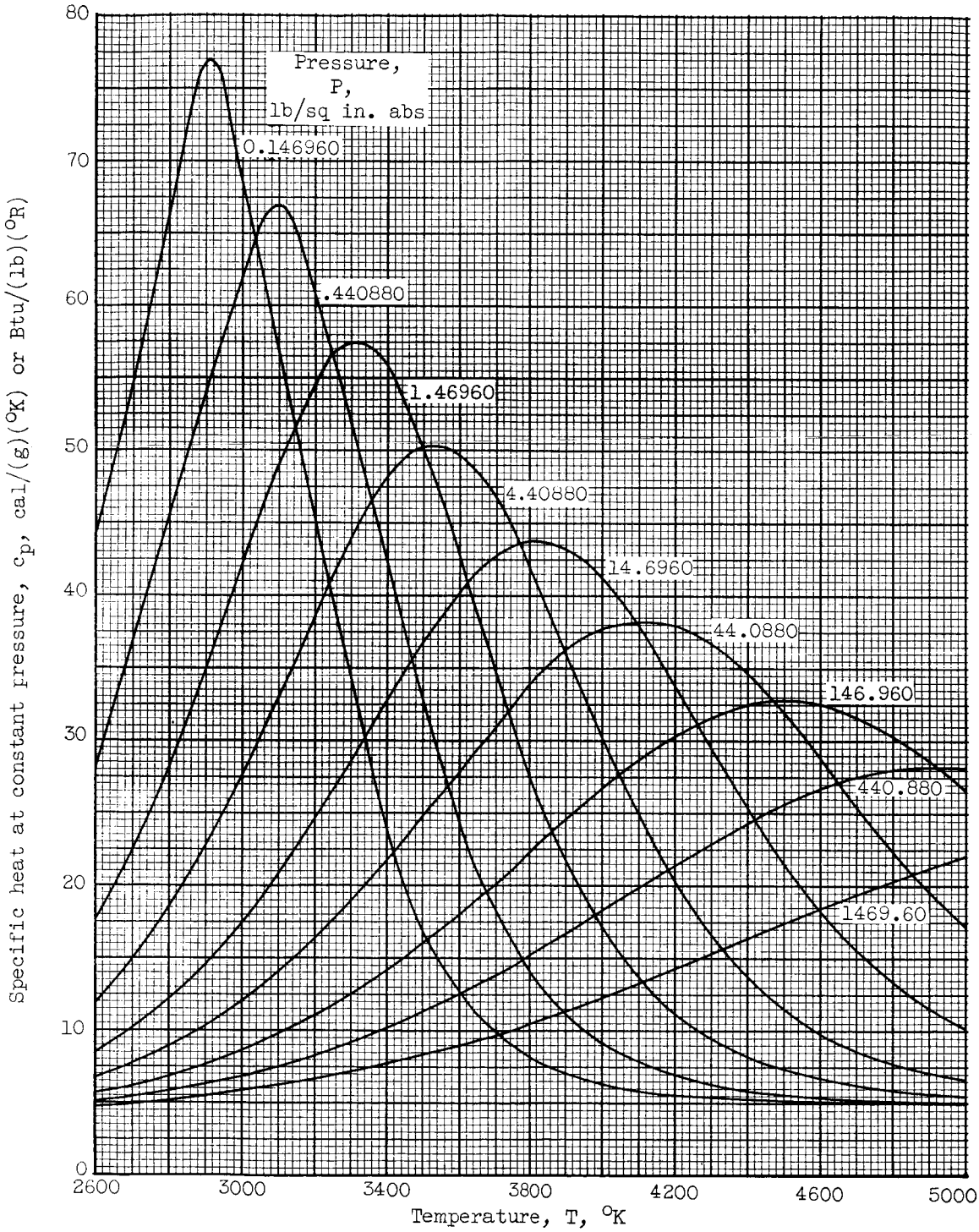
Figure 1. - Concluded. Specific heat at constant pressure of gaseous hydrogen for temperatures from 0° to 600° K.



(a) Temperature range, 400° to 2800° K.

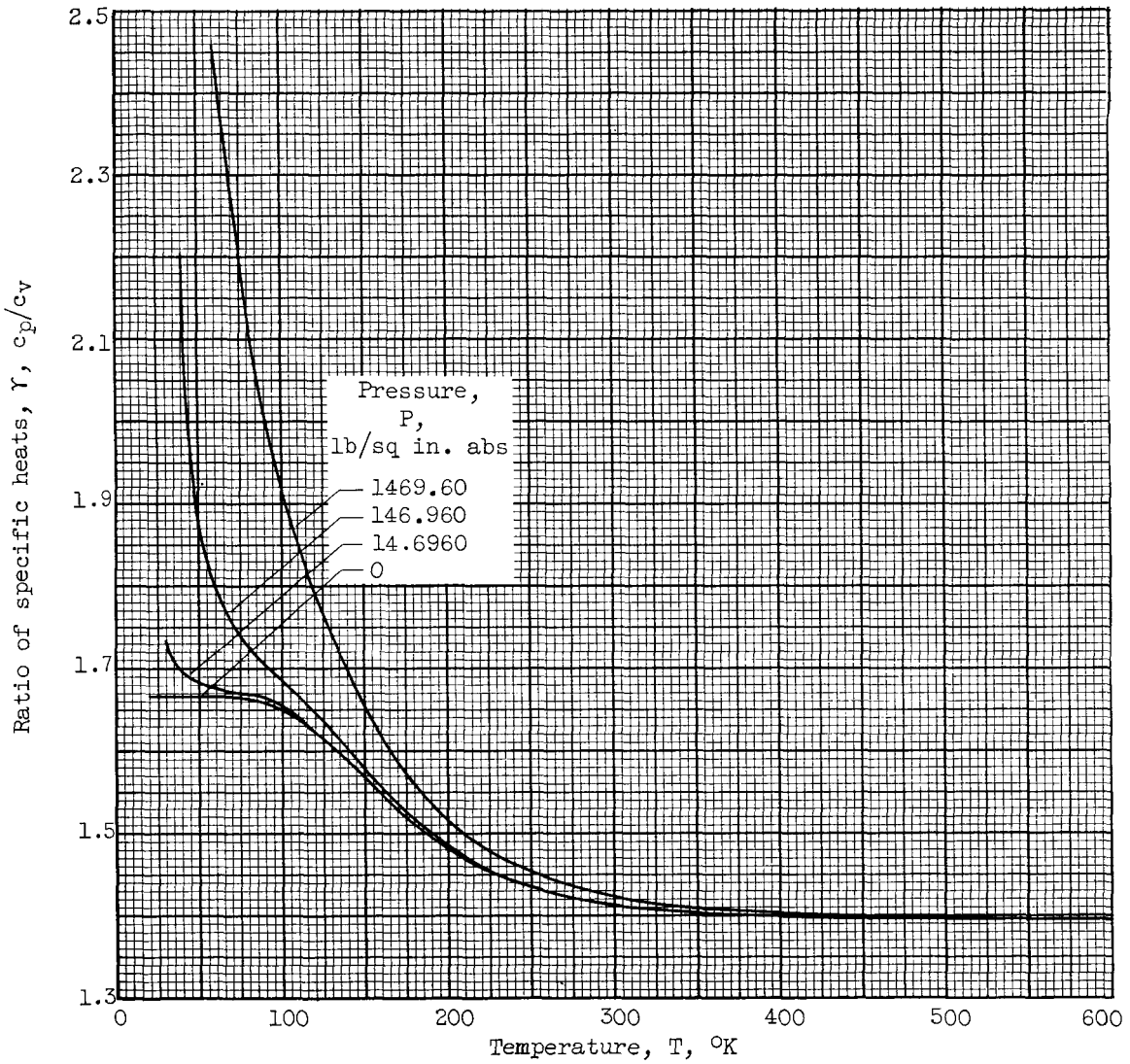
Figure 2. - Specific heat at constant pressure for gaseous normal hydrogen assuming equilibrium composition.

E-692



(b) Temperature range, 2600° to 5000° K.

Figure 2. - Concluded. Specific heat at constant pressure for gaseous normal hydrogen assuming equilibrium composition.

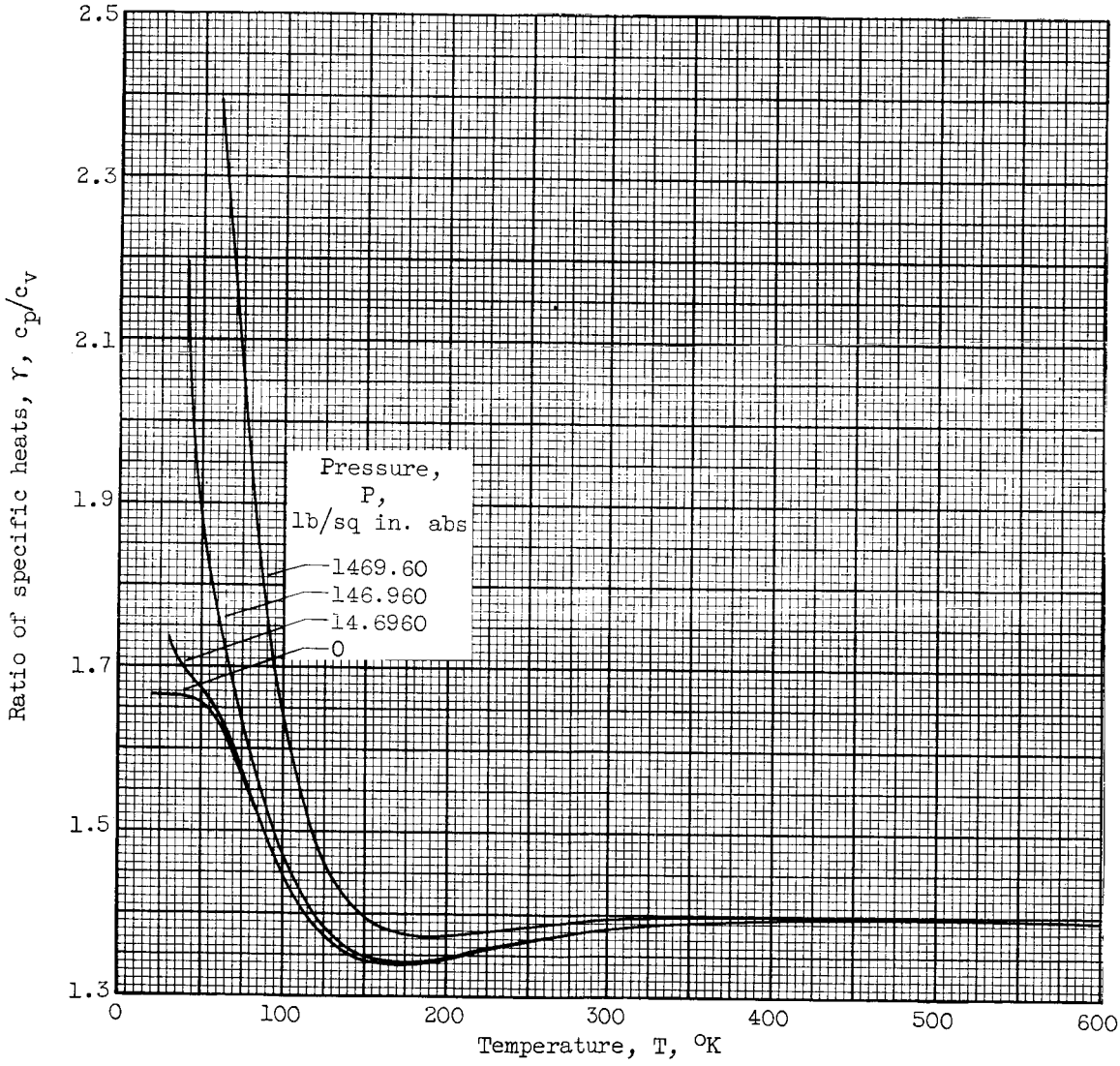


(a) Orthohydrogen.

Figure 3. - Ratio of specific heats of gaseous hydrogen for temperatures from 0° to 600° K.

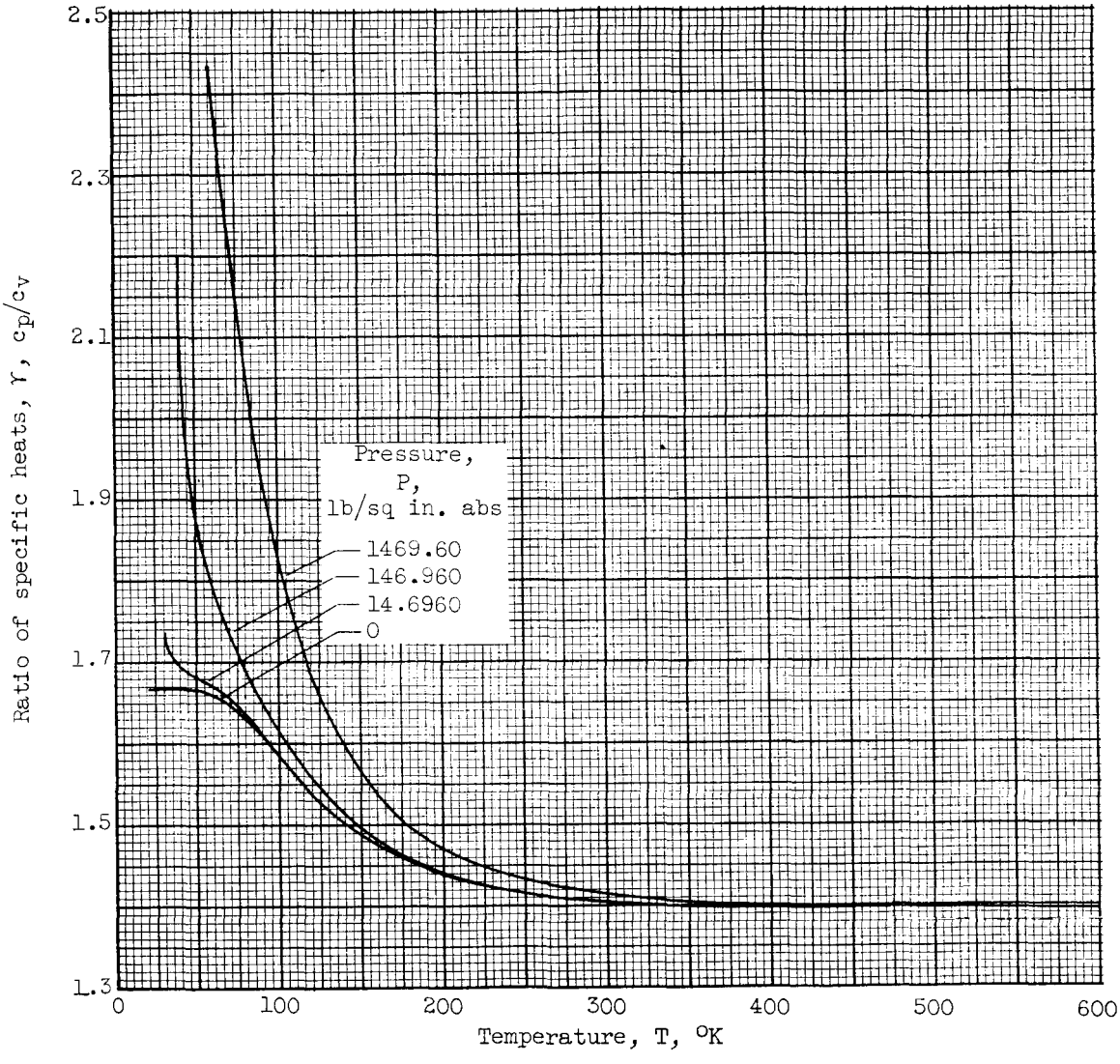
E-692

CT-7



(b) Parahydrogen.

Figure 3. - Continued. Ratio of specific heats of gaseous hydrogen for temperatures from 0° to 600° K.

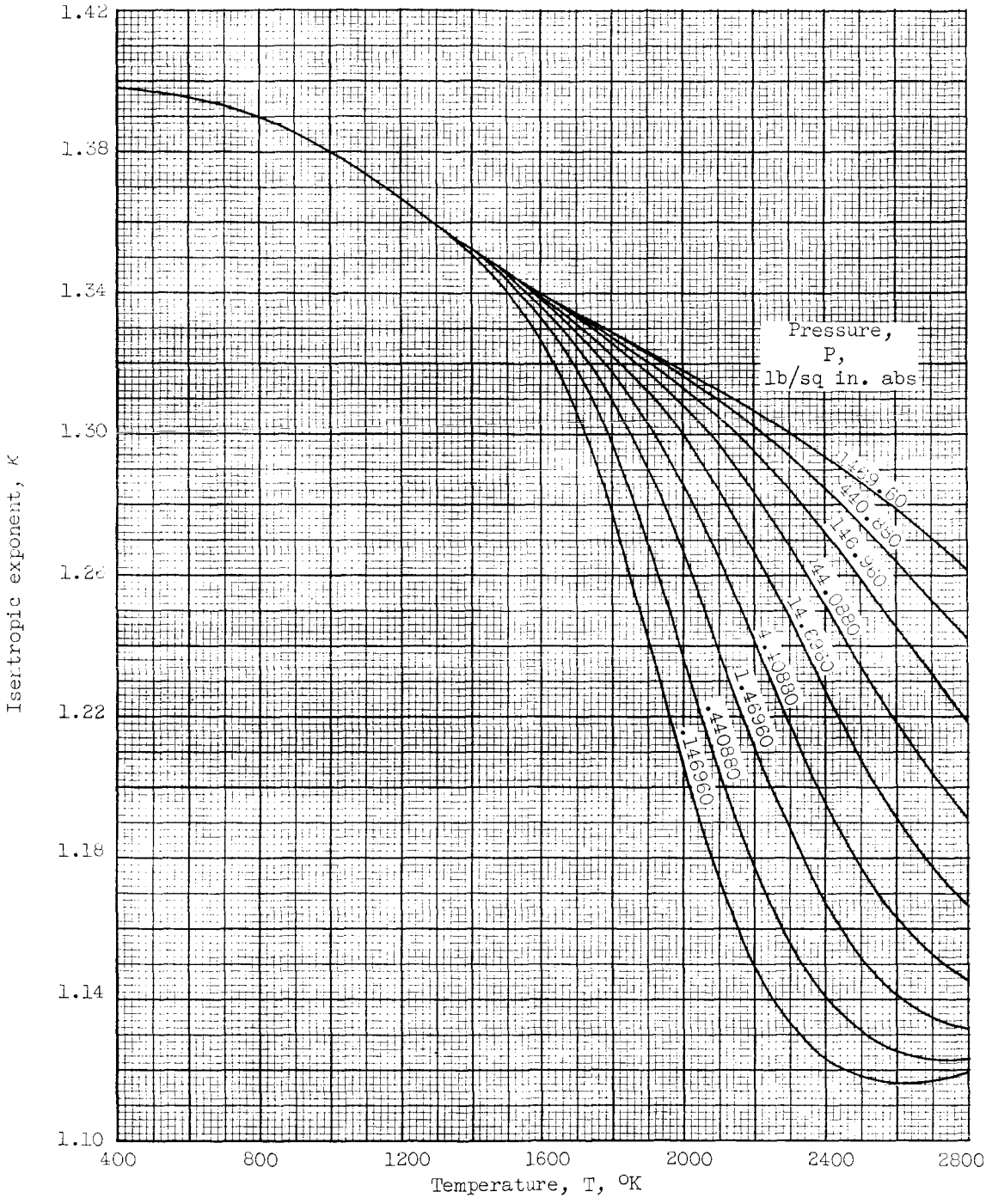


(c) Normal hydrogen.

Figure 3. - Concluded. Ratio of specific heats of gaseous hydrogen for temperatures from 0° to 600° K.

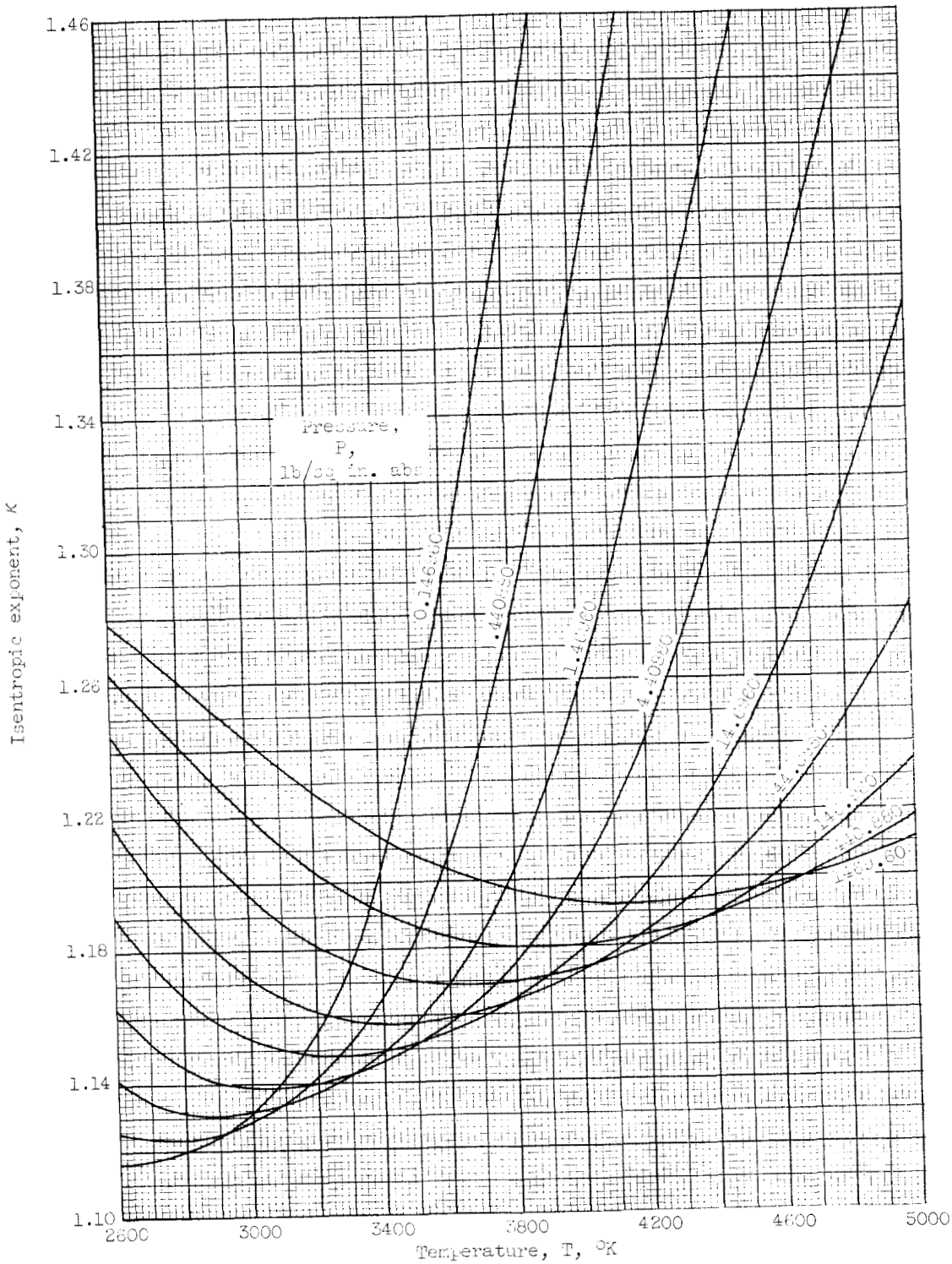
E-692

CT-7 back



(a) Temperature range, 400° to 2800° K.

Figure 4. - Isentropic exponents for gaseous normal hydrogen assuming equilibrium composition.

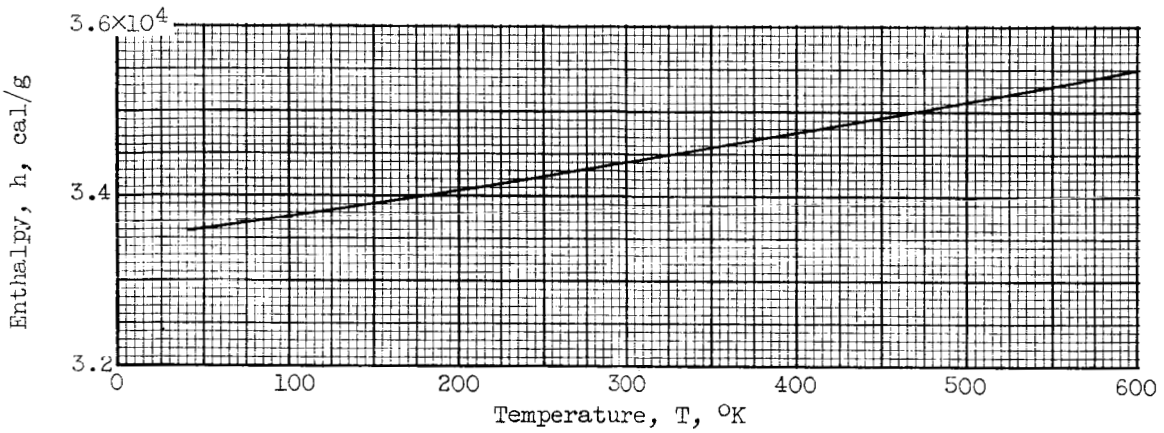


(b) Temperature range, 2800° to 5000° K.

Figure 4. - Concluded. Isentropic exponents for gaseous normal hydrogen assuming equilibrium composition.

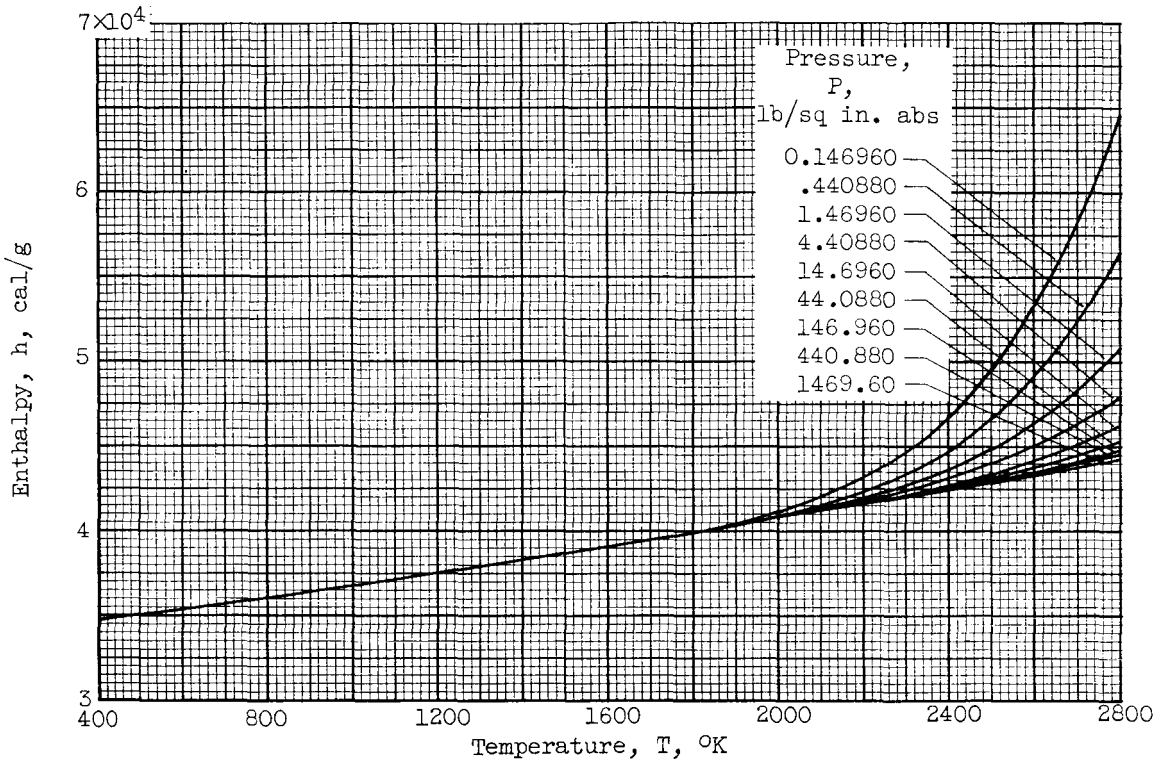
E-692

E-692



(a) Temperature range, 0° to 600° K.

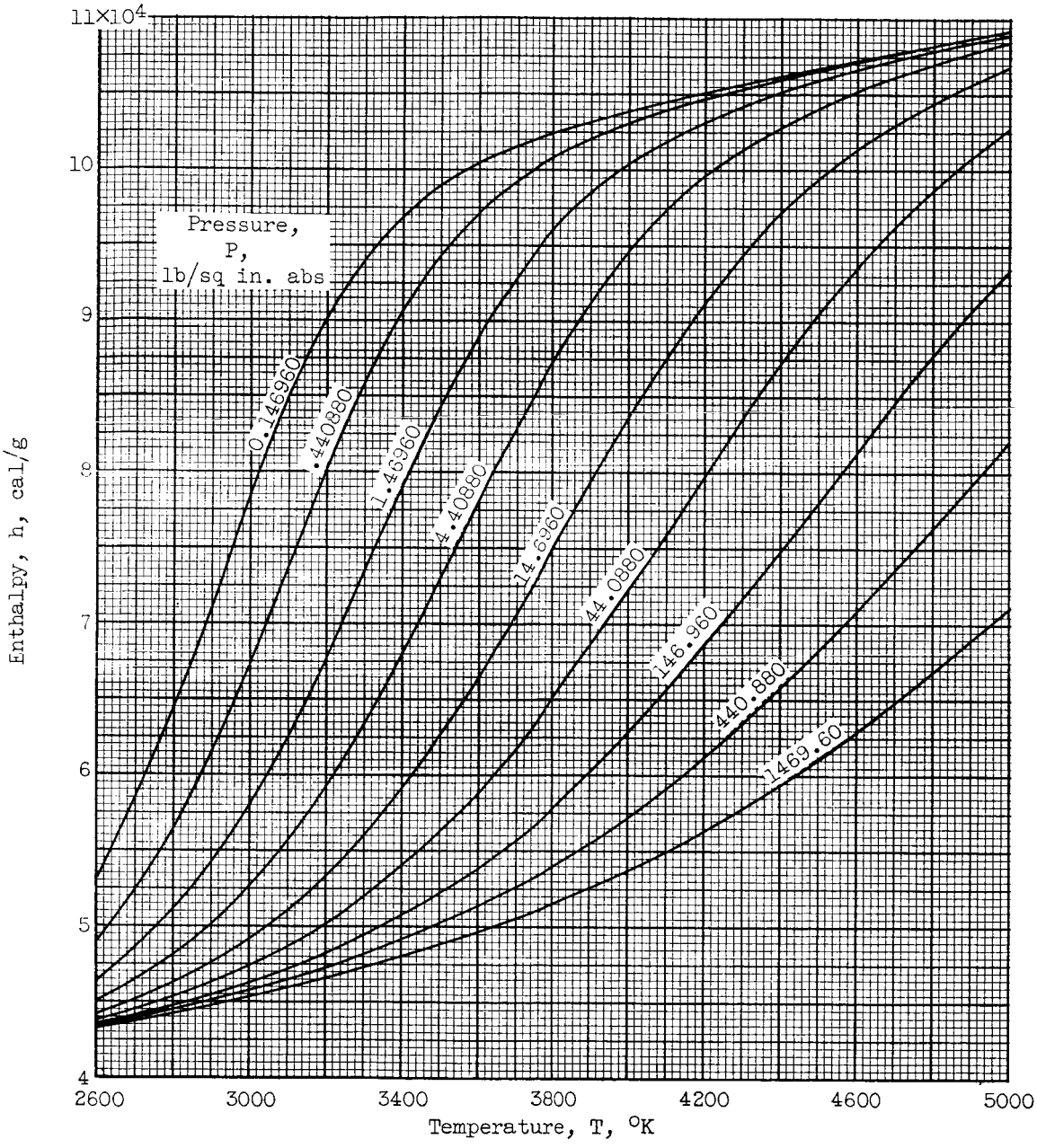
Figure 5. - Enthalpy of gaseous normal hydrogen assuming equilibrium composition. Base enthalpy at 0° K = 33,440.9 calories per gram (ref. 4).



(b) Temperature range, 400° to 2800° K.

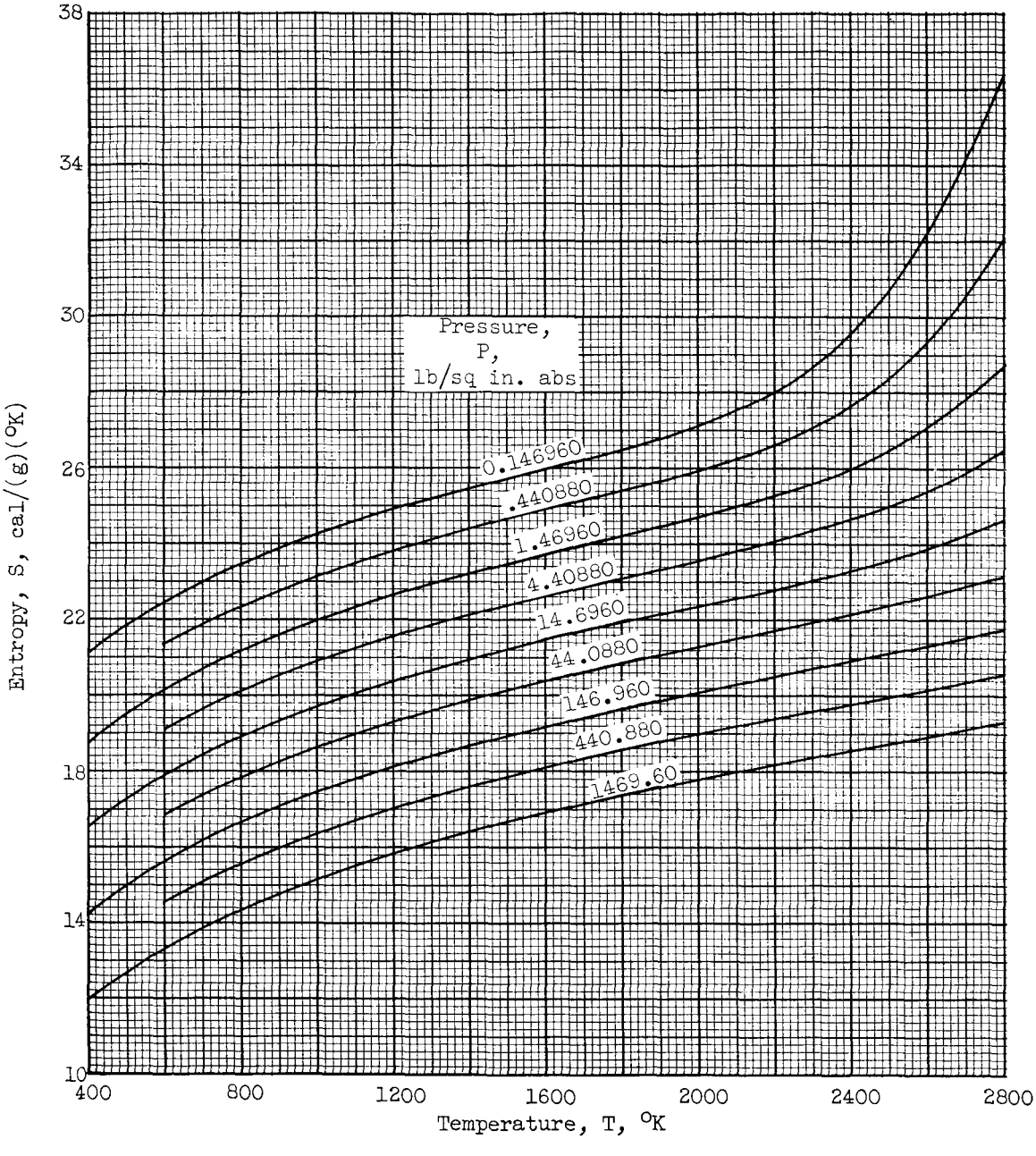
Figure 5. - Continued. Enthalpy of gaseous normal hydrogen assuming equilibrium composition. Base enthalpy at 0° K = 33,440.9 calories per gram (ref. 4).

E-692



(c) Temperature range, 2600° to 5000° K.

Figure 5. - Concluded. Enthalpy of gaseous normal hydrogen assuming equilibrium composition. Base enthalpy at 0° K = 33,440.9 calories per gram (ref. 4).

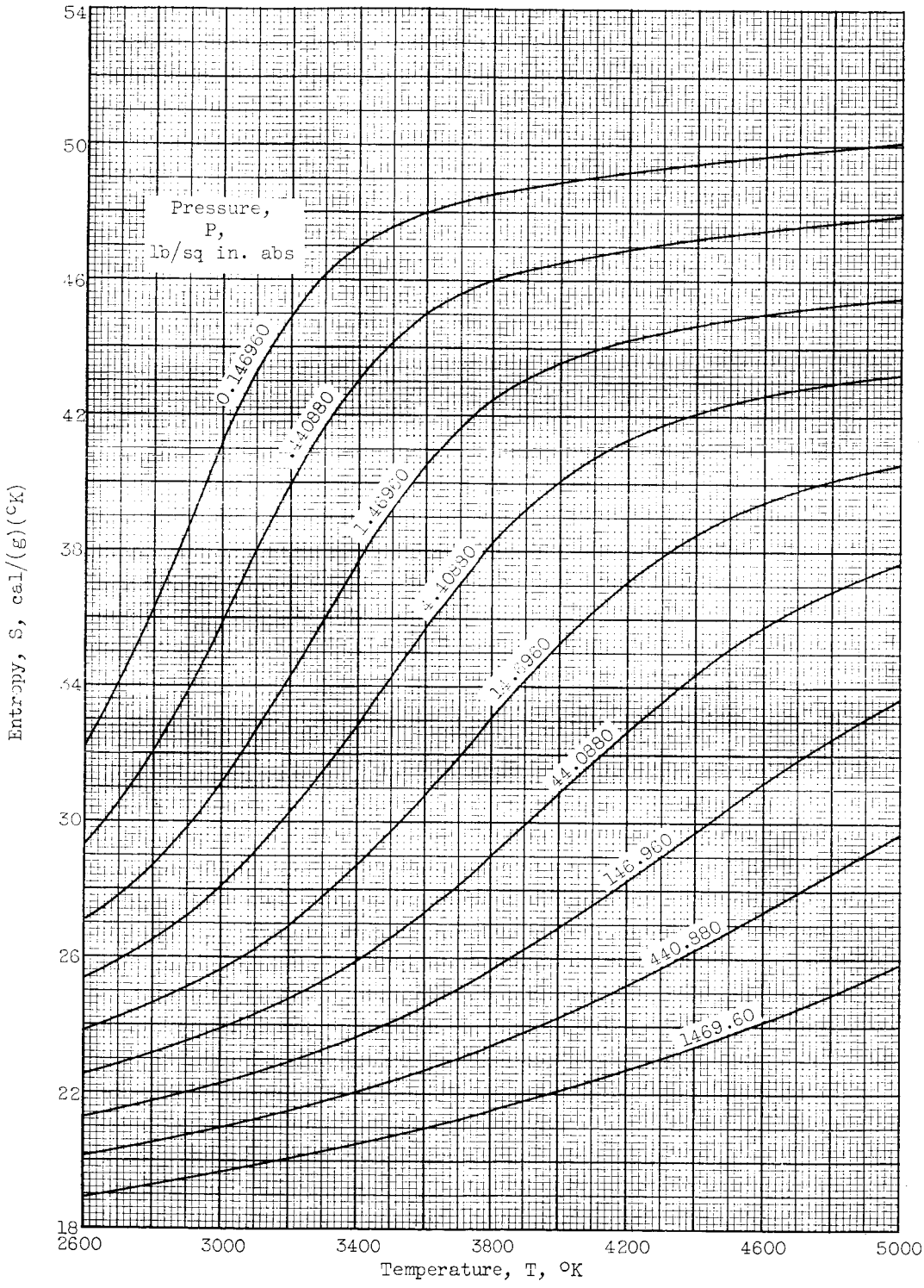


(a) Temperature range, 400° to 2800° K.

Figure 6. - Entropy of gaseous normal hydrogen assuming equilibrium composition.

E-692

CT-8



(b) Temperature range, 2600° to 5000° K.

Figure 6. - Concluded. Entropy of gaseous normal hydrogen assuming equilibrium composition.

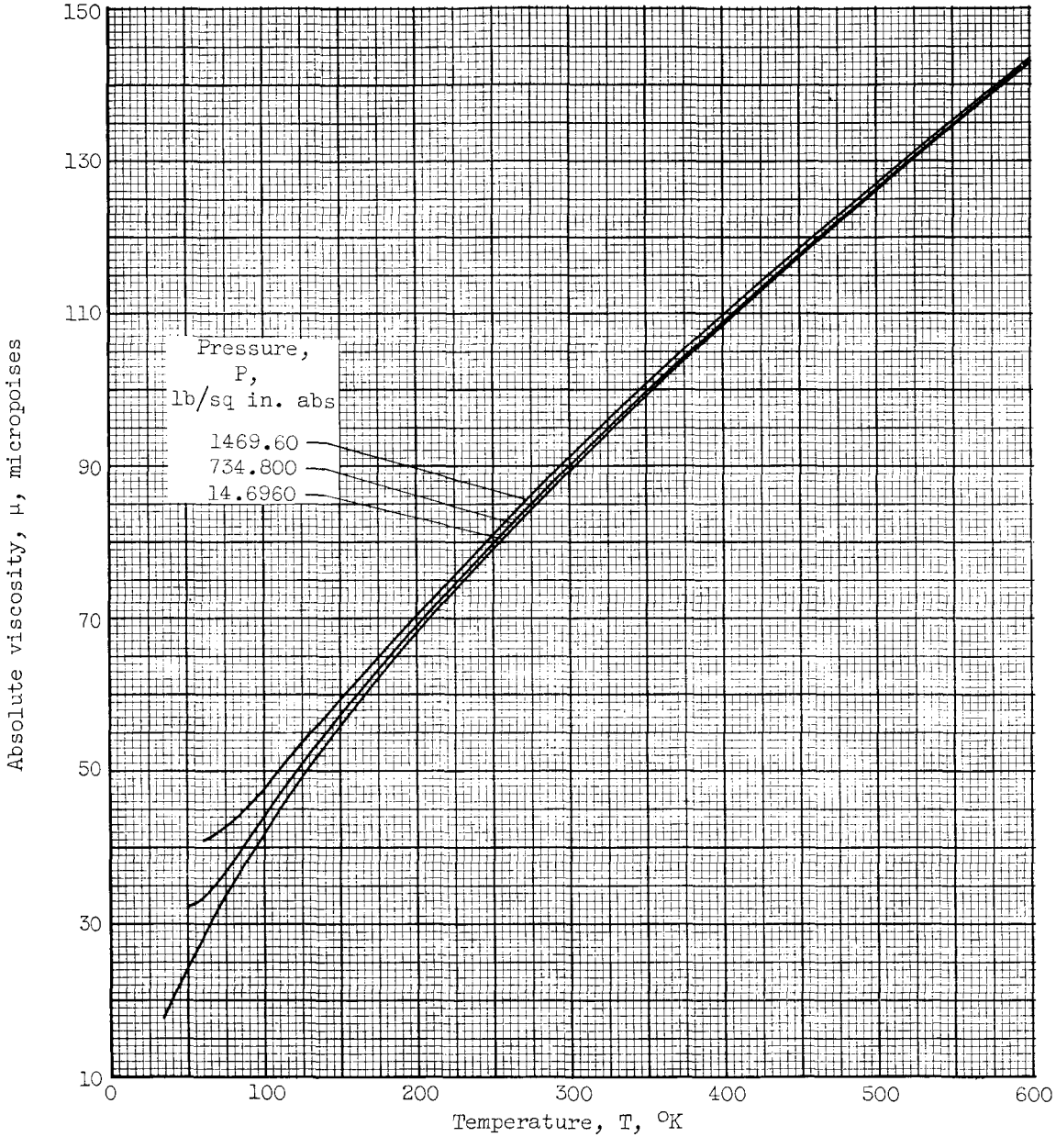
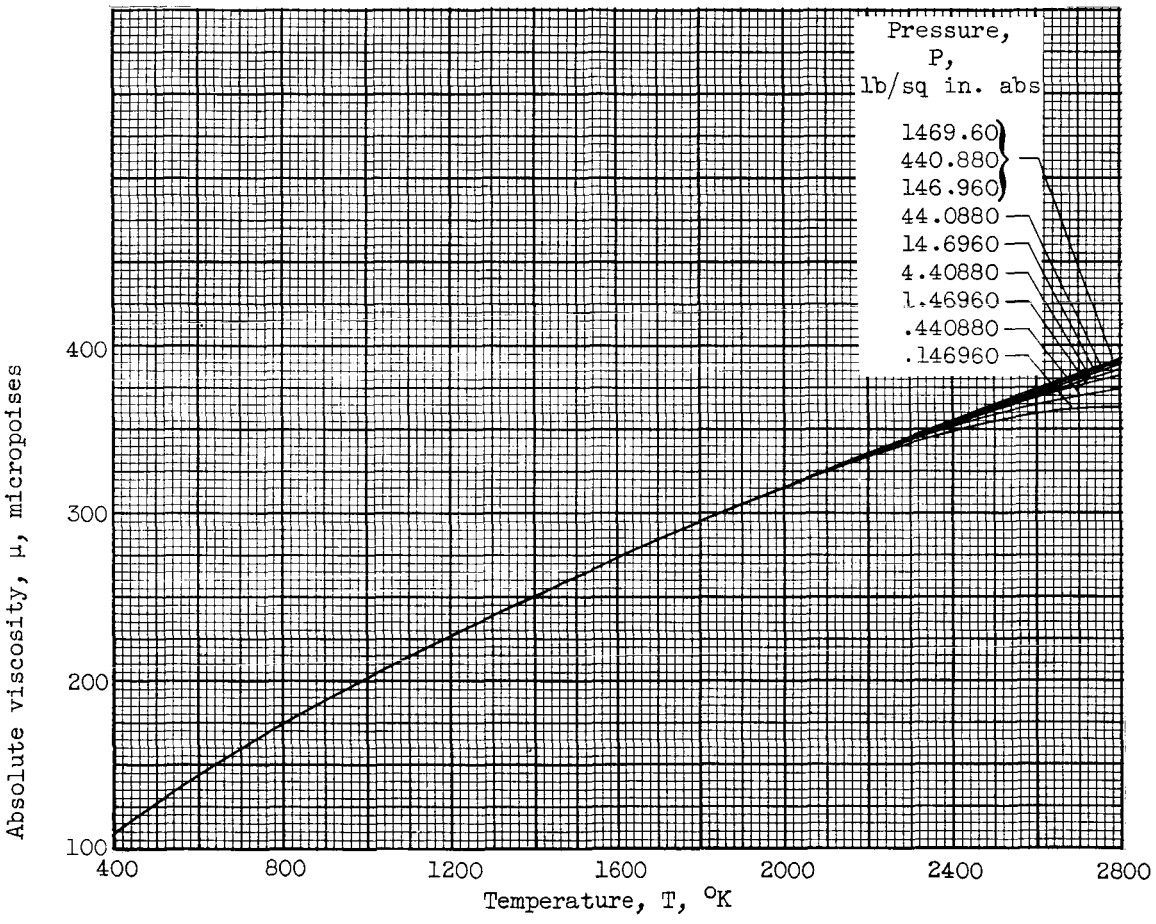


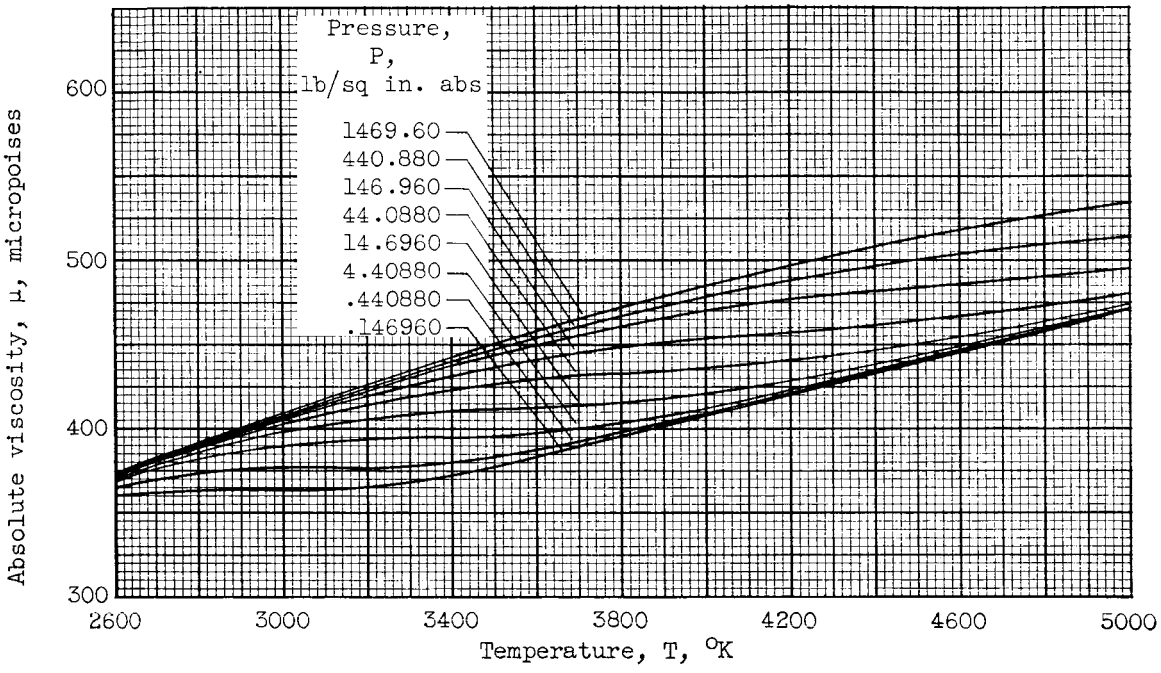
Figure 7. - Absolute viscosity of gaseous normal hydrogen, orthohydrogen, and parahydrogen for temperatures from 0° to 600° K.

E-692



(a) Temperature range, 400° to 2800° K.

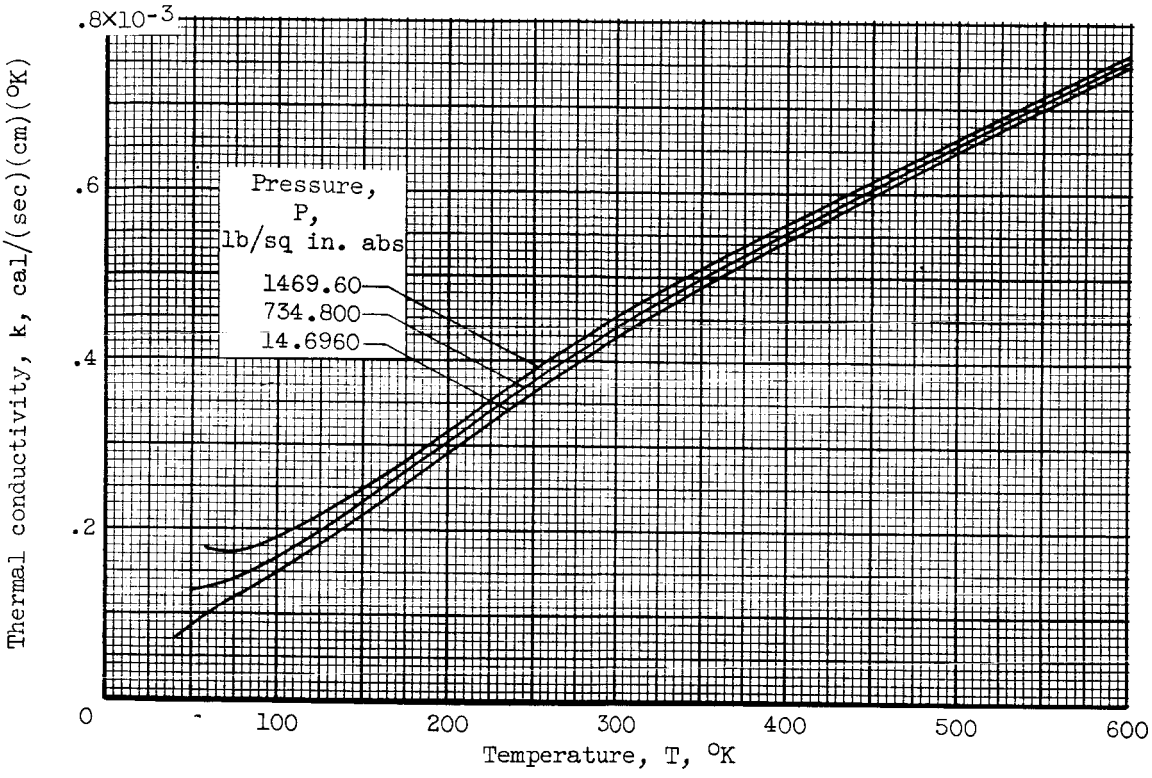
Figure 8. - Absolute viscosity of gaseous normal hydrogen assuming equilibrium composition.



(b) Temperature range, 2600° to 5000° K.

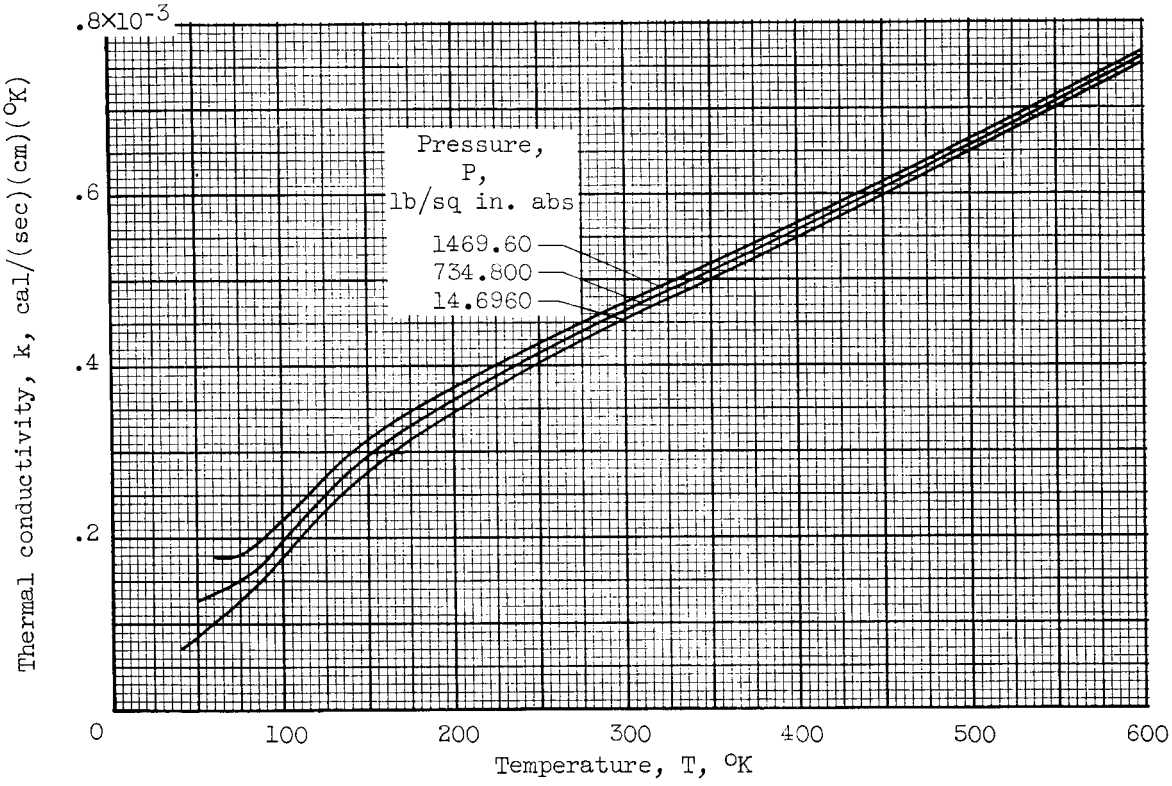
Figure 8. - Concluded. Absolute viscosity of gaseous normal hydrogen assuming equilibrium composition.

E-692



(a) Orthohydrogen.

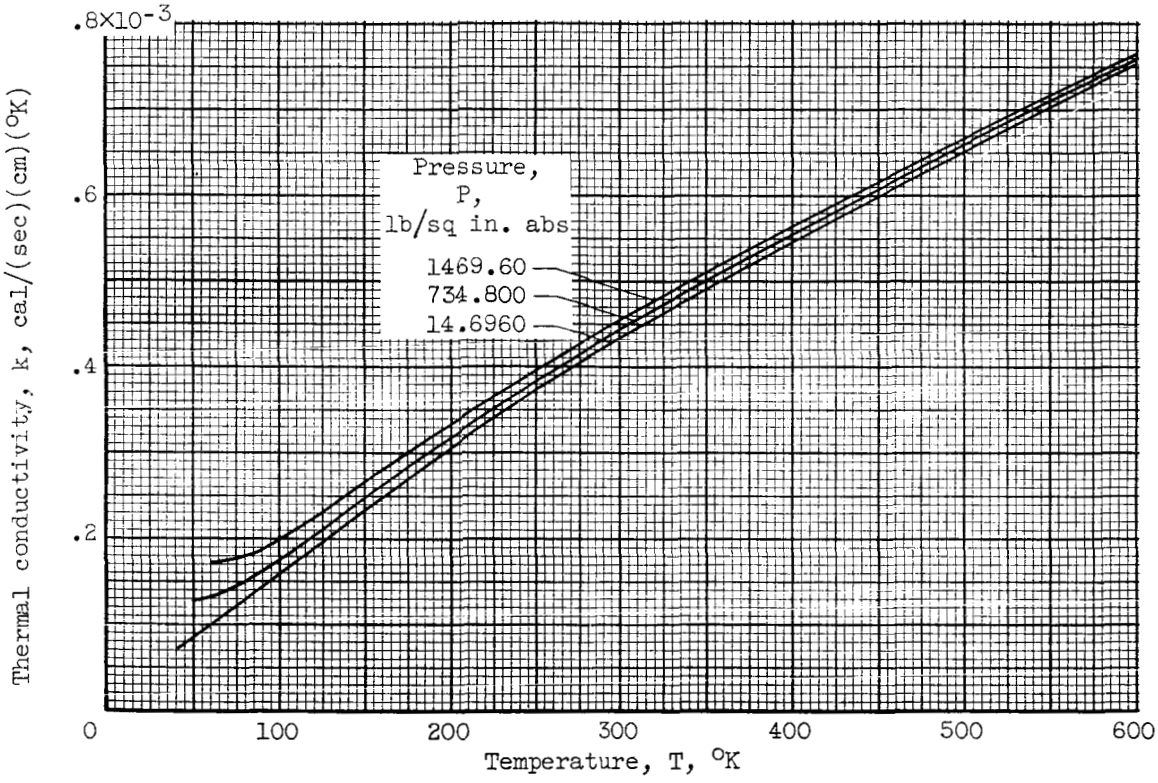
Figure 9. - Thermal conductivity of gaseous hydrogen for temperatures from 0° to 600° K.



(b) Parahydrogen.

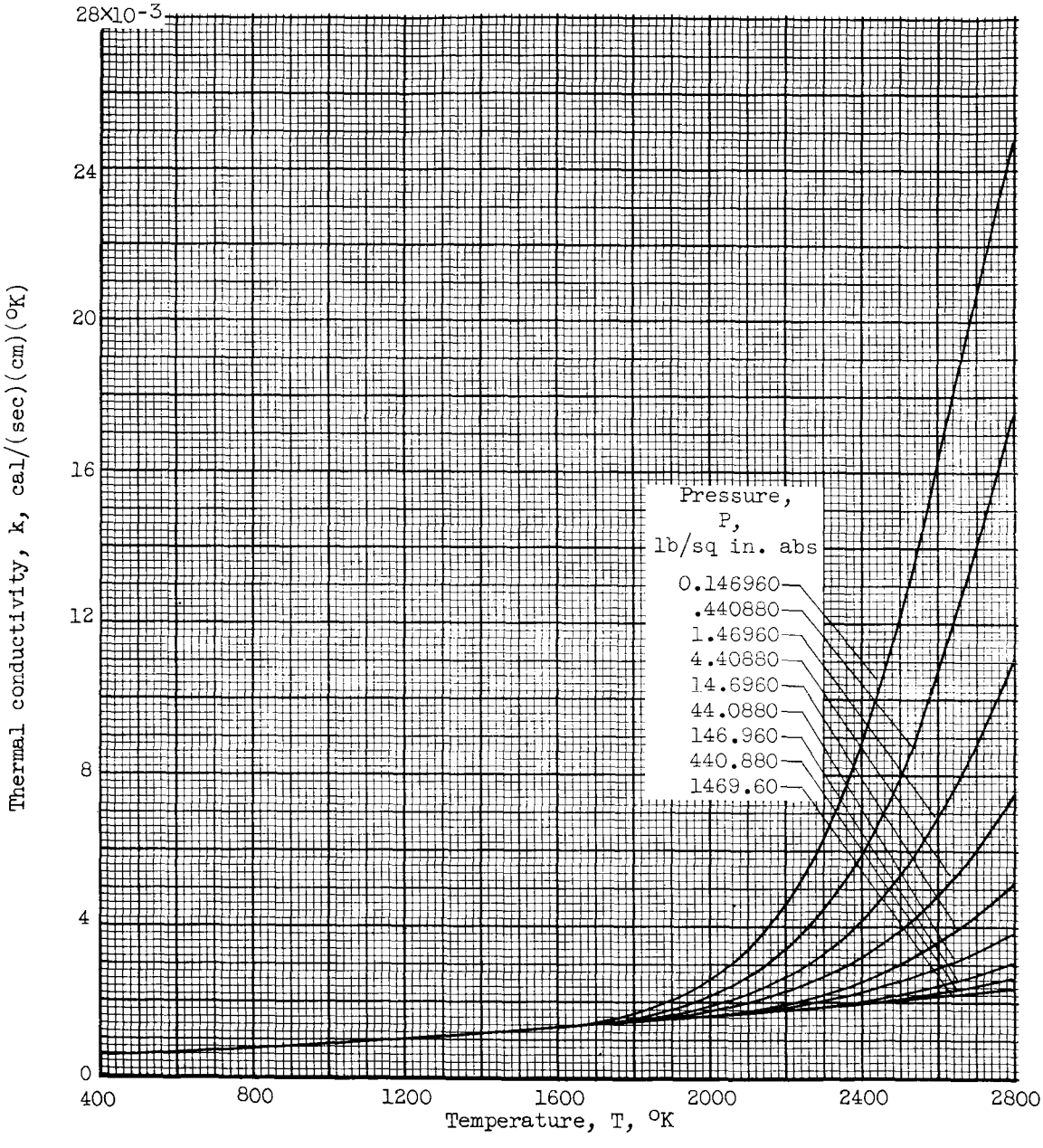
Figure 9. - Continued. Thermal conductivity of gaseous hydrogen for temperatures from 0° to 600° K.

E-692



(c) Normal hydrogen.

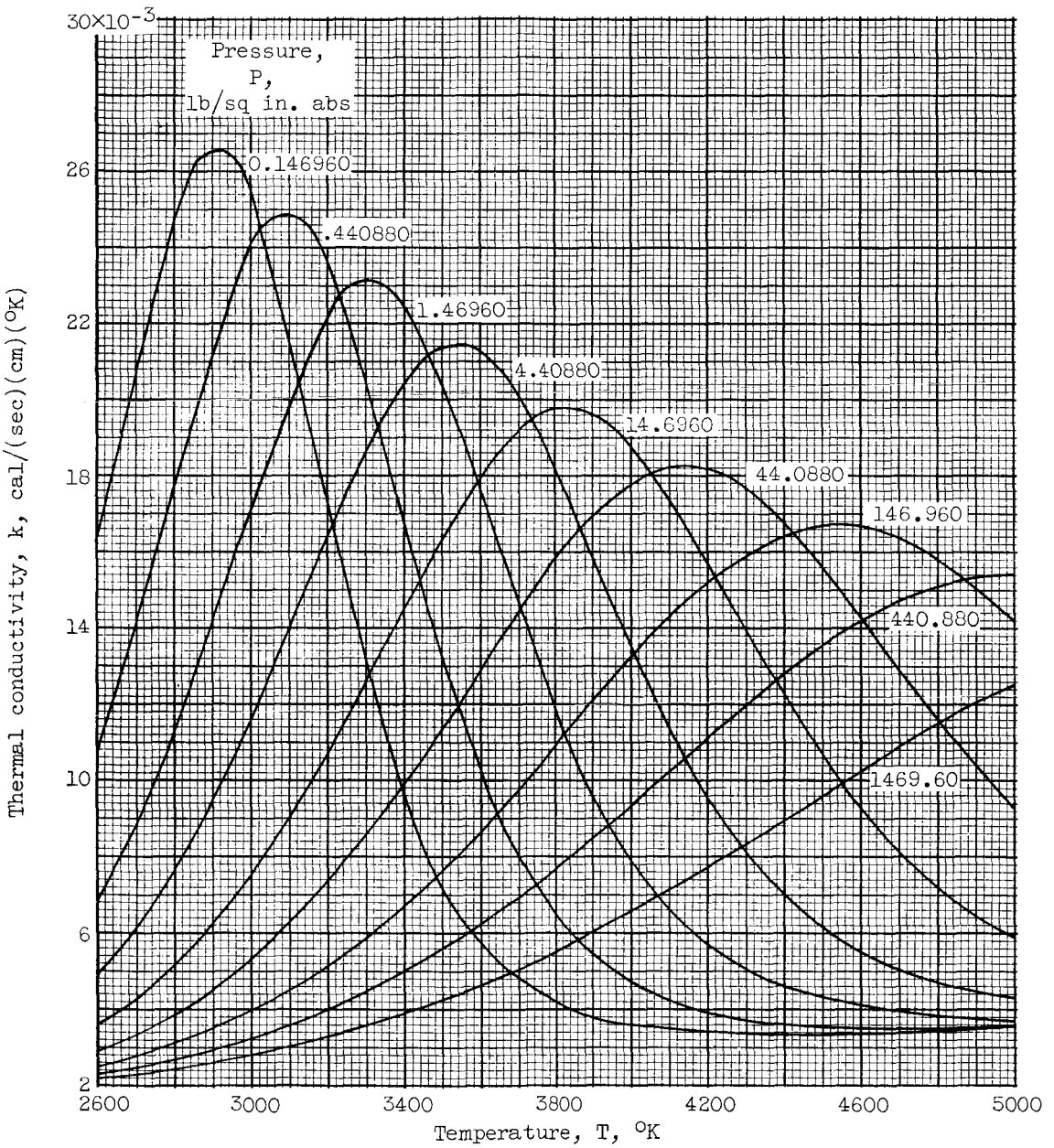
Figure 9. - Concluded. Thermal conductivity of gaseous hydrogen for temperatures from 0° to 600° F.



(a) Temperature range, 400° to 2800° K.

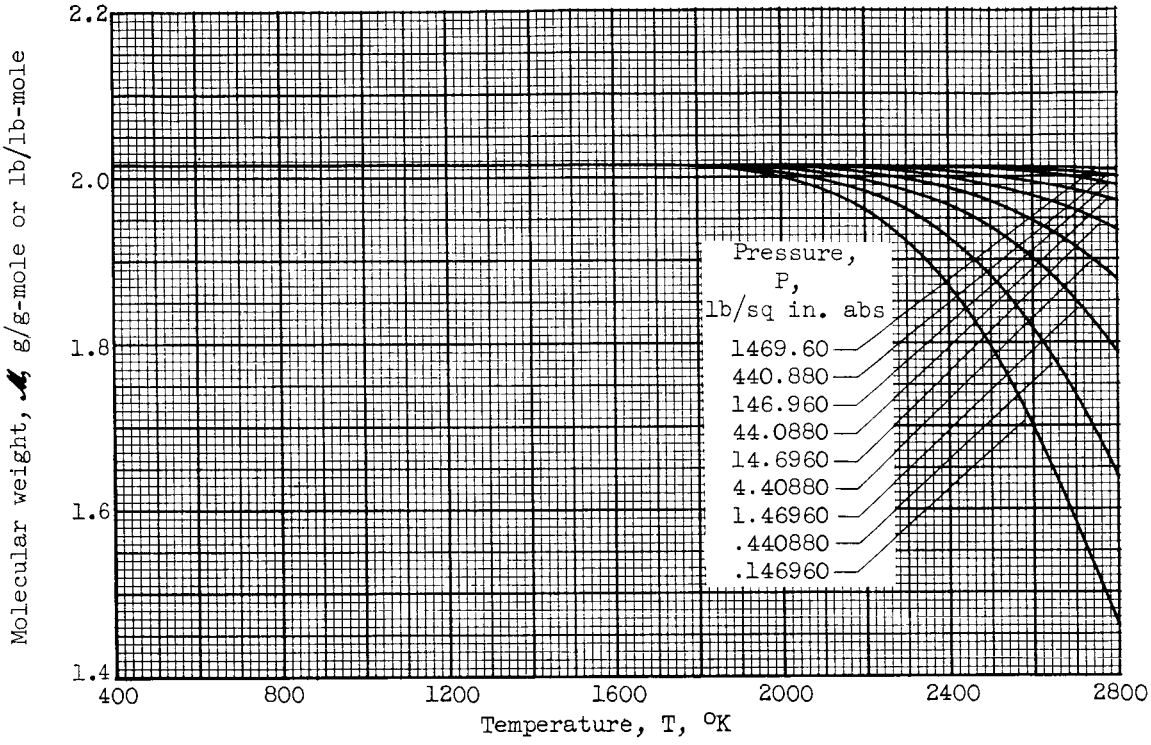
Figure 10. - Thermal conductivity of gaseous normal hydrogen assuming equilibrium composition.

E-692



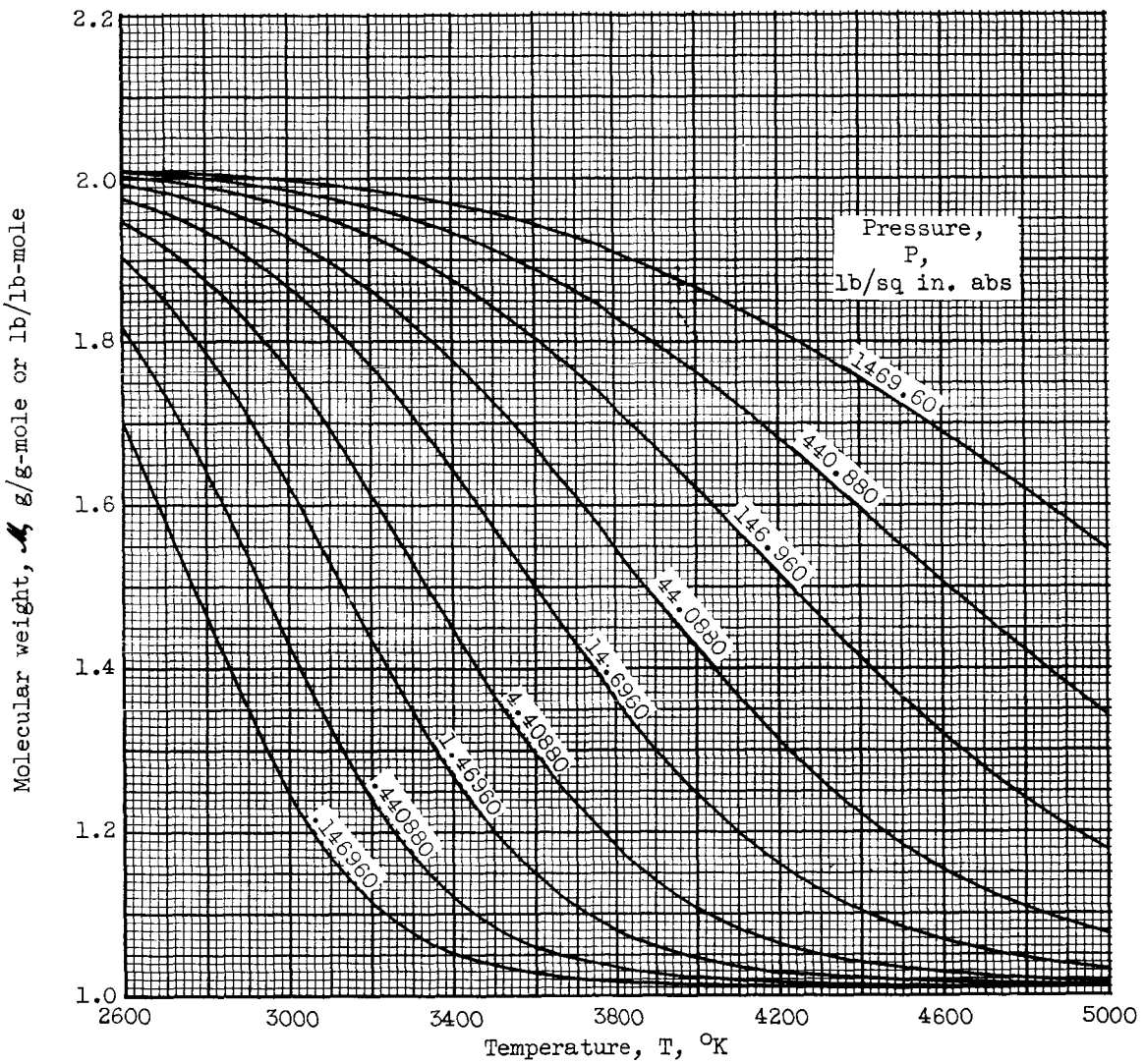
(b) Temperature range, 2600° to 5000° K.

Figure 10. - Concluded. Thermal conductivity of gaseous normal hydrogen assuming equilibrium composition.



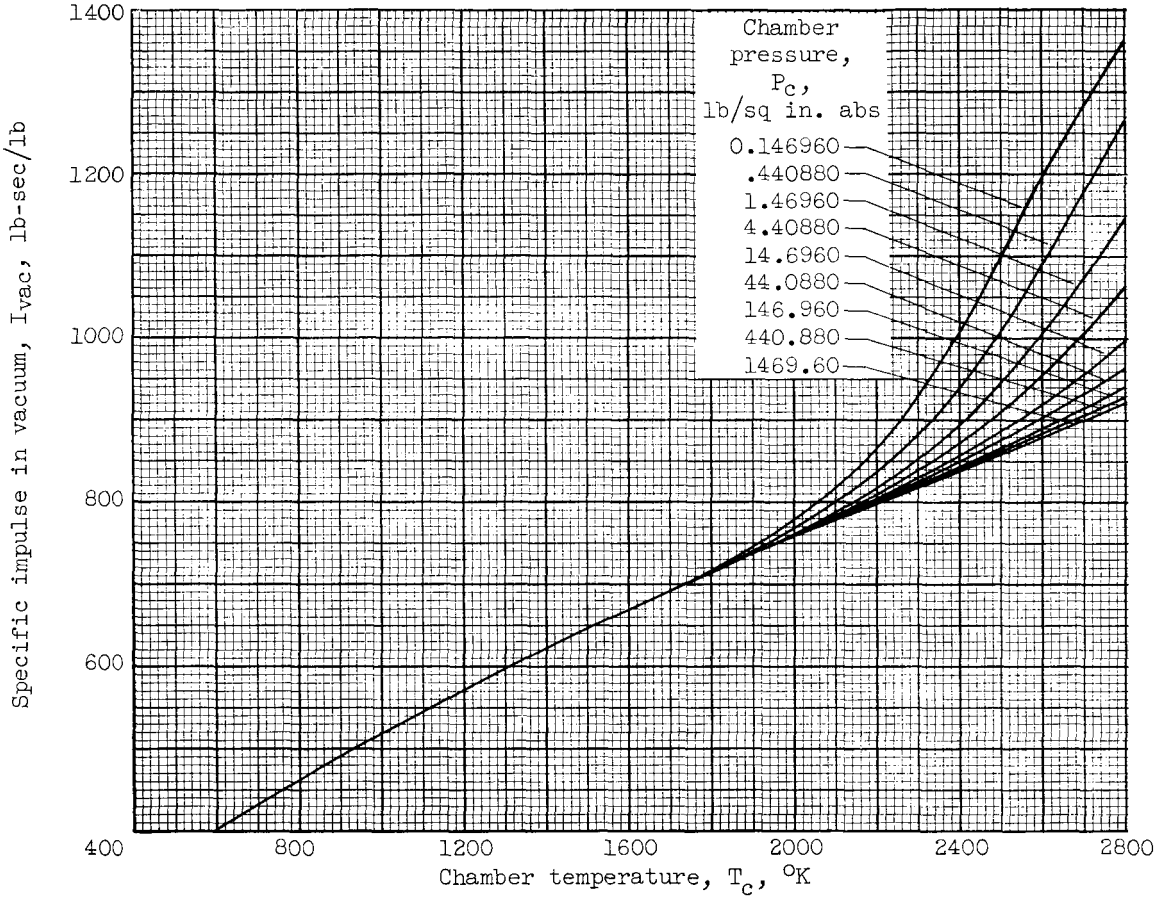
(a) Temperature range, 400° to 2800° K.

Figure 11. - Molecular weight of gaseous normal hydrogen assuming equilibrium composition.



(b) Temperature range, 2600° to 5000° K.

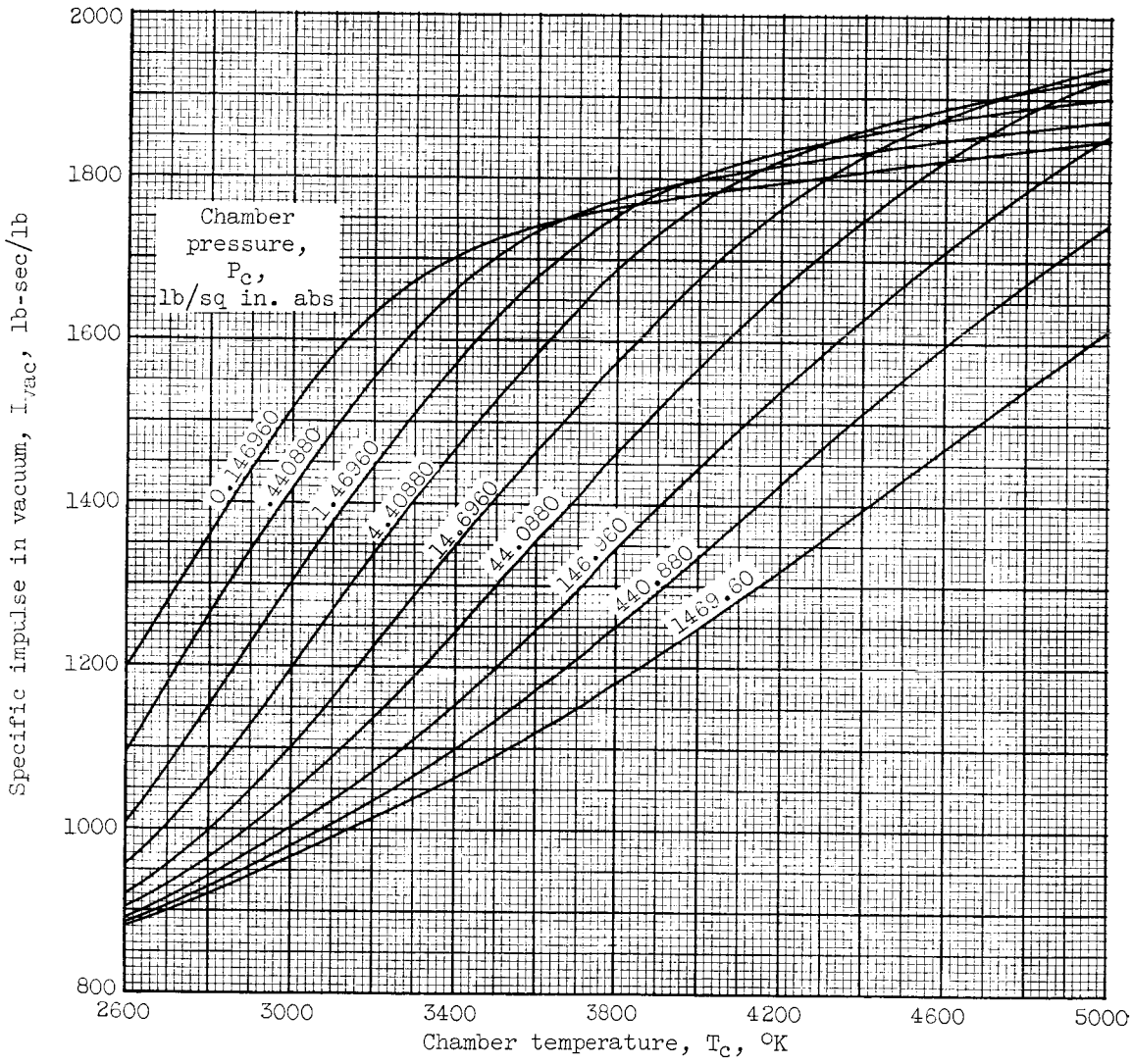
Figure 11. - Concluded. Molecular weight of gaseous normal hydrogen assuming equilibrium composition.



(a) Chamber temperature range, 400° to 2800° K.

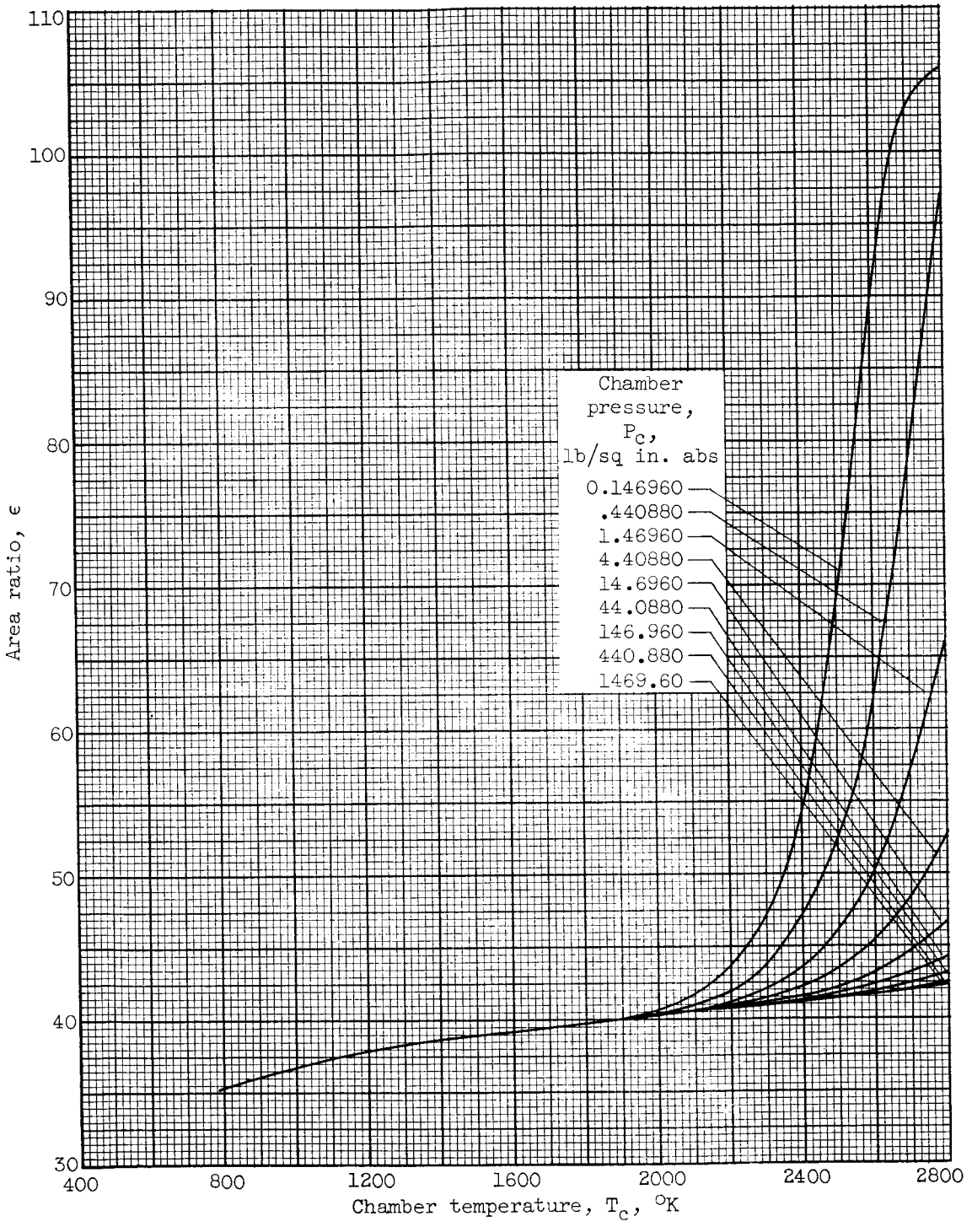
Figure 12. - Specific impulse in vacuum for gaseous normal hydrogen assuming equilibrium composition during an isentropic expansion to a pressure ratio of 1000.

E-692



(b) Chamber temperature range, 2600° to 5000° K.

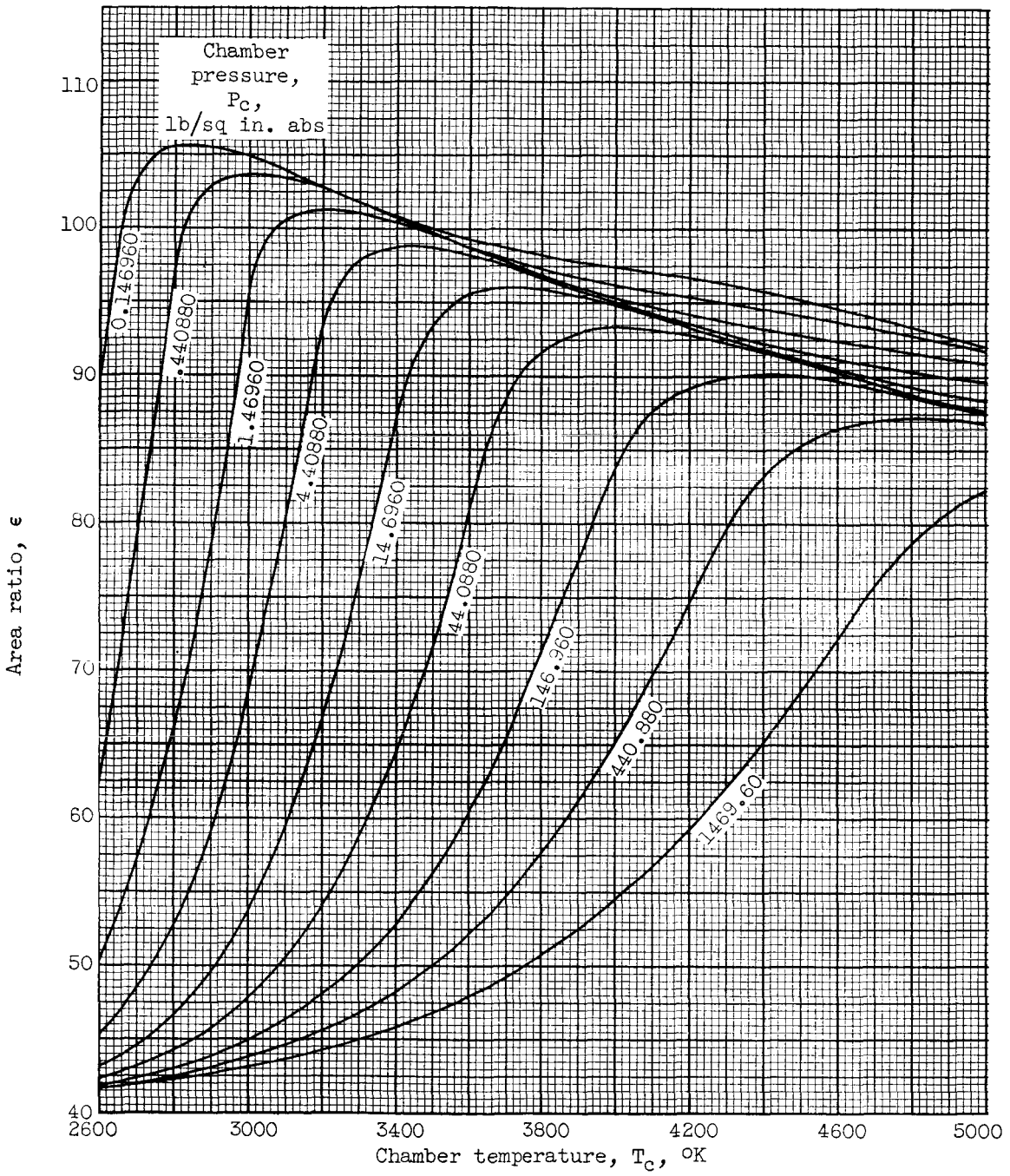
Figure 12. - Concluded. Specific impulse in vacuum for gaseous normal hydrogen assuming equilibrium composition during an isentropis expansion to a pressure ratio of 1000.



(a) Chamber temperature range, 400° to 2800° K.

Figure 13. - Theoretical ratio of nozzle area to throat area for gaseous normal hydrogen assuming equilibrium composition during an isentropic expansion to a pressure ratio of 1000.

E-692



(b) Chamber temperature range, 2600° to 5000° K.

Figure 13. - Concluded. Theoretical ratio of nozzle area to throat area for gaseous normal hydrogen assuming equilibrium composition during an isentropic expansion to a pressure ratio of 1000.