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PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

JULY 1, 1979 - SEPTEMBER 30, 1979

SUBMITTED TO: N.A.S.A.

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

PROGRESS REPORT: July 1, 1979 - September 30, 1979

Research Study: Warm/Cold Cloud Processes

Contract NAS8-33131

As in the previous two quarters, Mr. David A. Bowdle has continued to work under the direction of Dr. B. Jeffrey Anderson as USRA Visiting Scientist. His research during this period is described fully in the attached report.

No problems are known to exist that may impede progress.

Mr. Bowdle will continue as USRA Visiting Scientist during the next reporting period.

Respectfully submitted,

M. H. Davis
USRA/Boulder
Program Director

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THIRD QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: June 1 - August 31, 1979

BY: David A. Bowdle, USRA Visting Scientist, Marshall Space Flight Center

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months work has been accomplished under this contract in five principal areas:

1. Continuing technical assistance as needed in support of the Atmospheric Cloud Physics Laboratory (ACPL).

2. Attendance at the ACPL prime contractor's (General Electric) Interim Design Review (IDR) and the Principal Investigator's (PI) Preliminary Requirements Review (PRR) June 5-7 at Marshall Space Flight Center (MSFC).

3. A brief study of selected factors affecting warm cloud formation (as a result of concerns which were raised by the PI's during the IDR and PRR meetings). This study showed that the time of cloud formation during an arbitary expansion is independent of carrier gas composition for ideal gases and independent of aerosol concentration for low concentrations of very small aerosols.

4. Laboratory tests of the equipment and procedures for gravimetric evaluation of a precision saturator. The plumbing and flow controls have been completed and several tests have been run on the cold trap. The trap inlet froze shut during the initial runs; this problem was solved by replacing the original plastic inlet tubing with heated copper sheath tubing. Moderately large ice pellets or ice clusters ($\sim$0.5cm) were ejected from the trap outlet during portions of several runs. Heating the inlet line appeared to reduce this problem; but did not completely eliminate it. The inlet and outlet lines have been redesigned, replumbed, and are now ready for use. The present trap configuration is expected to achieve the high trapping efficiencies ($\sim$99.95%) required to develop a test procedure with a resolution of 0.05%.

5. A numerical feasibility study for the stable levitation of charged solution droplets by an electric field in a one-g static diffusion chamber. This technique is expected to be useful both for basic research in cloud microphysics and for evaluation of various low-gravity droplet handling techniques. This feasibility study was prepared for presentation at the NASA Severe Storms and Local Weather Review in Huntsville, Alabama, on September 12 and 13. The results of the study are described in Section II below.

II. Results

A. Concept and Operating Principles

The levitation technique uses an electrical potential (V) applied between two parallel plates separated by a distance (H) to support a layer of charged droplets against gravity (Fig.1). The interior surfaces of the two plates are covered with a thin layer of pure water. The top plate is maintained at a temperature slightly higher than the bottom plate. This temperature difference produces at steady state a linear temperature gradient (T) and a linear water vapor pressure gradient (P_w) between the plates (Fig. 2). The exponential dependence of the equilibrium water vapor pressure (P_s) on temperature produces a parabolic supersaturation profile (P_w/P_s) within the chamber, with saturation at each water surface.

If a charged salt aerosol (e.g., NaCl) is introduced into the chamber between the plates, each solution droplet which forms from the salt aerosol will, at steady state, achieve a stable equilibrium at some given level in the lower portion of the chamber. This stability arises because of the simulataneous force balance on the droplet (between the electrostatic force and the gravitational force) and thermodynamic equilibrium of the droplet (ambient water vapor pressure equal to the equilibrium water vapor pressure at the droplet surface). If the droplet rises above this equilibrium position in the chamber, it encounters an ambient water vapor pressure higher than its equilibrium value and tends to grow in response. However, the resulting increase in mass disturbs the force balance, and the increased gravitational force tends to bring the droplet back to its equilibrium level. Similarly, if the droplet falls below its equilibrium level, it tends to evaporate and hence to be returned toward its equilibrium level.

Obviously, this type of stable equilibrium is possible only in the portion of the static diffusion chamber where the supersaturation increases with height. Hence, the levitation technique will work just as well in a diffusion chamber with a subsaturated lower plate surface. This configuration may be obtained by substituting for the pure water surface on the bottom plate either an aqueous salt solution, as Sun et al reported, or a flat surface of solid ice.

The levitation technique described here differs from that reported by Sun et al in several ways. Most importantly, this levitation technique takes advantage of the Kohler theory (Fig. 3) for the equilibrium water vapor supersaturation over the surface of an inactivated solution droplet of a given size and containing a given salt mass. Sun et al had minimal control over their salt masses, and, therefore, they probably utilized the metastable equilibrium of activated droplets (depicted on each Kohler curve by points to the right of the maximum). This type of operating condition apparently restricted them to a droplet layer at or near saturation (100% relative humidity), which condition can be achieved only in a diffusion chamber with a subsaturated bottom plate.

B. Applications

The modification proposed here offers a great deal of flexibility. For example, if a monodisperse dry salt aerosol can be produced with a monodisperse charge distribution, and if the salt mass is small enough so as to remain unactivated by the highest supersaturation in the chamber, then a single thin layer of monodisperse droplets will be supported at some given level in the lower portion of the chamber. In this configuration, the chamber can be used to study a wide range of cloud microphysical problems (Table 1). For example, if the salt mass changes during the course of an experiment, the equilibrium conditions for the droplet will change in a measurable way. Hence, this technique can be used to investigate gas and particle scavenging with a sensitivity not even approachable with standard microchemical trace analysis. It can also be used to investigate other areas of aerosol physics and droplet growth, such as measurement of phoretic forces and aerosol soluble mass, verification of Kohler theory and the new CCN theory described in the 2nd quarterly report, and growth of unactivated and nearly activated or just activated droplets. It may also be possible to use this technique to map changes in steady state vapor fields produced by perturbations at the chamber boundary or near probes inserted into the chamber.

Alternate configurations would utilize a polydisperse charge distribution on a monodisperse salt aerosol, resulting in distinct multiple layers of droplets in the chamber. This configuration would, of course, be limited to small charge numbers so that one droplet layer could easily be distinguished from another. The logical extension of this configuration is a polydispersity of both salt mass and droplet charge, resulting in a continuous cloud of droplets throughout the lower portion of the chamber.

Several areas of investigation in ice physics seem accessible using the various configurations described above. For example, freezing of isolated solution droplets could easily be observed. Water vapor profiles around ice crystals, particularly those which are neither growing nor evaporating, could be observed with a thin droplet layer. Transient vapor fields around growing ice crystals may be observable with a thick droplet layer. Finally, using a configuration very similar to that of Sun et al, except with colder temperatures, it may be possible to produce a stable layer of free-floating ice crystals or to study an isolated free-floating crystal. One might also suspect, if this technique is feasible for studying ice crystals, that it may be applicable for studying other types of crystals in a free floating mode as well.

C. Operating Limits

This levitation technique obviously offers a great deal of flexibility and versatility, although not without a price. The electrical fields or charge numbers required to support even moderate droplet sizes can quickly become impractical or unattainable in the laboratory. More seriously, the electrostatic and hydrodynamic forces on the droplets can actually alter the microphysical quantities of interest, such as the equilibrium water vapor pressure, droplet growth and evaporation rates, and even droplet shapes and radii of curvature. The following section describes the operating range and limits of the levitation technique.

The levitation technique is limited by Brownian motion to particle diameters larger than about 0.3 to 0.5 μm (Fig. 4). The average Brownian displacement for particles smaller than this size quickly becomes significant, particularly over the extended experiment time for which this technique is well suited. In fact, the instantaneous Brownian velocity of a given droplet at any given time is significantly larger than its average Brownian velocity; this instantaneous velocity remains larger than the sedimentation velocity for particle sizes well above 0.5 μm diameter. It may well turn out that these large instantaneous velocities prevent these very small droplets from achieving stable equilibrium. In addition, these small droplets are difficult to detect using the required remote telescope (by comparison, the optics for the Atmospheric Cloud Physics Laboratory (ACPL) cloud chambers are designed to detect 2 μm radius droplets; some improvement is possible in the laboratory by increasing light intensities). The combination of these two effects may restrict the operating range of the levitation technique to droplets somewhat larger than 0.5 μm diameter.

The plate temperature differences required for stable support of droplets between about 1 and 100 μm radius lie between 0.1 and 1.0°C (Fig. 5); these conditions are readily achievable and have been used for several years in continuous flow diffusion chambers (CFD's). The very low supersaturations required for stable levitation of drops between 100 and 10,000 μm (1cm) radius would call for plate temperature differences between 0.01 and 0.1°C; these conditions are expected to be quite difficult to achieve in the laboratory (by comparison, the diffusion chambers being developed for ACPL are designed for a plate temperature spatial uniformity of 0.01°C). It may be possible to use as temperature controllers certain constant temperature physical processes whose critical temperatures differ by only a small amount (for example, phase changes near the triple point and the ice point, or phase changes with solutal freezing point depression or vapor pressure elevation). An alternate means for achieving such low supersaturations may be available with the subsaturated lower plate configuration. This configuration depresses the supersaturation everywhere within the chamber except at the top plate. By careful choice of plate temperatures and bottom plate condition, it may be possible to produce quite low supersaturations inside the chamber with good spatial resolution.

Dry aerosol sizes required to produce the desired droplet sizes range from about 0.1 μm to 2.0 μm radius for droplets between 1 and 100 μm radius and 2.0 μm to 215 μm radius for drops between 100 and 10,000 μm radius. Of course, for the very large drops, a large plate spacing would be required to prevent significant gradients in supersaturation across the drop body. The combination of the above effects may restrict the operating range of the levitation technique to droplets smaller than about 100 μm radius.

The electric field and charge number limits for the levitation technique are shown in Fig. 6 . For charge numbers at the Rayleigh limit, the effective surface tension of the drop is reduced to zero. The drop then becomes unstable and is subject either to charge loss or to large amplitude oscillations which disrupt it. For charge numbers somewhat below the Rayleigh limit, alterations in the equilibrium water vapor pressure above the drop and in drop growth and evaporation rates, due to the high drop charging, are expected to become significant. On the other hand for electric fields at the Taylor limit, the drop becomes elongated and develops a point instability at its two ends. This point then releases the instability by means of charge or mass loss, or both. For electric fields somewhat below the Taylor limit, alterations in the equilibrium vapor pressure above the drop and in drop growth and evaporation rates due to the induced charge separation and change in drop shape, are again expected to become significant. Finally, for high drop charging in high electric fields, the two effects combine to "pinch off" the operating range accessible to the levitation technique at charge and field levels significantly lower than would occur if each effect were operating independently.

The relationships presented in Fig. 6 suggest another use for the levitation technique, in which the existence of the Rayleigh and Taylor limits is used to advantage. Namely that, this technique is an ideal means by which to investigate the conditions and mechanisms of electrical breakdown in a moist, droplet filled atmosphere with a carefully controlled and accurately known relative humidity. For example, the Rayleigh boundary and the "pinched-off region" of high drop charging and high field strength can be accurately mapped. A particularly interesting region to investigate is the Taylor limit. The breakdown voltage for air tends to be in the range of ten Kilovolts per cm, and it shows significant variations with gas pressure and composition. Dawson and his colleagues at the University of Arizona performed an elegant set of experiments in which they determined the electrical breakdown mechansim at the surface of hanging water drops, as a function of drop curvature and field strength. Similar experiments have been performed for drops falling in a wind tunnel. However, no comparable experiments have apparently been carried out for free floating drops in a calm, stable atmosphere. It is conceded that the results of this type of investigation may not be directly applicable to the atmosphere; however, Dawson attempted just such an application from the results of his "hanging drop" studies. He also used the results of these studies to good advantage in the interpretation of his later work on falling drops. The results of a comparable study on stably levitated drops are expected to be similarly fruitful.

D. Sensitivity

It is useful at this point to examine the sensitivity of the levitation technique to changes (or errors) in the various parameters which enter into the equilibrium conditions (Figs. 7-11). The starting relationships are the electrical/gravitational force balance, the Kohler equation, and the static diffusion chamber supersaturation profile. (Fig. 7) Assuming that these relationships hold, the equilibrium differentials are easily determined (Fig. 8). Logarithmic forms are used for convenience in deriving the final relationships. Activation relationships (Fig. 9) are easily derivable or obtainable from Fletcher, Mason, and Byers. Finally, the equilibrium differentials can be combined as shown in Fig. 8, rewritten in terms of the activation relationships in Fig. 9, and expressed in exceedingly simple form as shown in Fig. 10. This final expression relates changes in selected parameters to changes in other parameters, assuming that equilibrium is maintanined throughout. The coefficients of these differential changes are easily evaluated and are shown in Fig. 11.

Similar sensitivity studies may be performed for the more exact expressions which incorporate buoyancy, phoretic, and Brownian effects into the force balance; electrical effects and the new CCN theory into the Kohler equation; and wall effects or subsaturated lower plates into the supersaturation profiles. Likewise, when the equilibrium differentials shown in Fig. 8 are combined, other variables can be eliminated so that the final equilibrium differential includes drop growth rates or ramp rates in the plate temperatures.

As an application of the sensitivity study which was performed, consider the problem of selecting the optimum means of measuring scavenging rates. Assume constant charge (dq = 0). This problem then reduces to a determination of the relative sensitivity of droplet position change (dz) for a constant electric field (dE=0) and the electric field change (dE) required to maintain the droplet at a constant position in the chamber. To increase the sensitivity of the detection technique, it appears to be desirable to maximize the coefficient of the scavenging term (dM_s) while at the same time minimizing the coefficient of the detection term (dE or dZ). Thus, the sensitivity of the field change technique is maximized (Fig. 11) for drops near activation ($X = r_c/r \gtrsim 1$), for which scavenging amplifications by a factor of three to five are passible. The larger amplifications which appear for conditions quite close to activation (X = 1) would be quite difficult to attain in practice because finite increases in soluble mass (ΔM_s) would actuallly cause activation and destablization.

On the other hand, the sensitivity of the position change technique is maximized for drops near saturation ($X = \sqrt{3}$) and drop position near H/2 . However, these two extremes are incompatible for a water/water plate configuration. For drops near saturation and drop positions near the bottom plate, scavenging amplifications by a factor of about 2.5 are possible. For drops near activation and drop positions near H/2, amplifications by factors of about three to five are again reasonable. For drops roughly midway between saturation and activation, and drop positions roughly midway between the bottom plate and the chamber midpoint (i.e. near H/4), amplifications by a factor of three seem reasonable.

Assume that a factor of three amplification is attainable. It is then possible to determine the limiting resolution of the detection technique for scavenging. It appears that in either the case of dz = 0 or dE = 0, the detection limit will be based on the limiting resolution for position detection. We assume a limiting resolution for the unaided human eye of 0.1 mm (0.01 cm) at a distance of about 20 cm, an optical telescope with a magnification of 10X (without degraded resolution), and a droplet suspended about 1.0 cm above the bottom plate. We then find position resolution of about 0.1% and a scavenging resolution of about one-third that value, or about 0.03%. Assume a dry particle radius of about 0.1 μm, or a dry mass of about 10^{-14}gm. It then appears that this detection system may be capable of a limiting scavenging resolution as low as about 3×10^{-18} gm for these particles (about 3×15^{-15} gm for a 1.0 μm radius dry particle).

As a second application to this sensitivity study, consider the spread produced in the thin droplet layer by polydispersity in charge or soluble mass. Thus, a 10% polydispersity in charge will produce only about a 2-3% spread in droplet layer thickness for nearly activated drops about one-third of the chamber height above the bottom plate - but about a 17% spread for drops near saturation just above the bottom plate. On the other hand, a 10% polydispersity in soluble mass will produce nearly a 25% position spread for drops near saturation just above the bottom plate and about a 10% position spread for nearly activated drops one-third of the plate spacing above the bottom plate.

E. Development Plan

It can be seen that the proposed levitation technique is potentially a very versatile research tool for studying problems in cloud microphysics and techniques for low-gravity remote drop positioning as well as for evaluating particular microphysical experiments for inclusion on ACPL. We therefore propose to build a prototype levitation chamber and test it at several selected drop sizes (Table 2). Using the experience gained with this prototype chamber, we expect to develop a precision levitation chamber for careful measurements of scavenging rates and other selected cloud microphysical problems.

Auxilliary equipment required for this work will include various aerosol generation techniques. For example, very large drops which can be levitated only by very large drop charging in very high electric fields must probably be generated directly (near their final size). This restriction arises because small atomized droplets of highly concentrated solution, which can easily grow into very large drops in high relative humidities, cannot stably hold the large quantities of charge required to levitate the very large drops. Standard large-drop generating techniques are available; however, as an alternative, it may be possible to charge up drops which are beginning to grow in the chamber. For the smaller sized droplets, standard atomization techniques are expected to be adequate. Droplet position detection is expected to be accomplished using standard optical telescopes. This system is expected to be adequate for droplets larger than a few microns in radius. For smaller droplets, such arrangements as a travelling light source (laser) and a yoked detector, or other comparable configurations as well, are possible. The primary development effort is expected to be directed forward the design of the levitation chamber itself and the selection of the appropriate droplet generation techniques.

III <u>Planned Effort</u>

During the final three months of the current contract year work is expected to be performed in six principal areas:

1. The NASA review on 12-13 September.

2. Continuing technical assistance with the design and development of ACPL. This effort is expected to be concentrated during 9-17 October, the first phase of the MSFC Critical Design Review (CDR) at Hunstville on the General Electric Contract for ACPL.

3. Final development of the gravimetric test as a means of evaluating the saturator performance. Concurrently with this work will be a comparison of the gravimetric and the vapor pressure techniques for testing the saturator and evaluation of a plasma (glow-discharge) technique for cleaning the saturator wicking surfaces.

4. Final documentation of the following research:

a. Sensitivity of warm cloud development to cloud updraft and aerosol nucleus spectrum.

b. Sensitivity of warm cloud formation to composition, aerosol spectrum, and initial temperature and pressure of the carrier gas.

c. Gravimetric verification of the saturator performance.

5. Numerical solution of the CCN activation polynomial and preparation of a professional paper on the results.

6. (If time permits) Design and construction of prototype static diffusion chamber with applied electric field for droplet levitation studies.

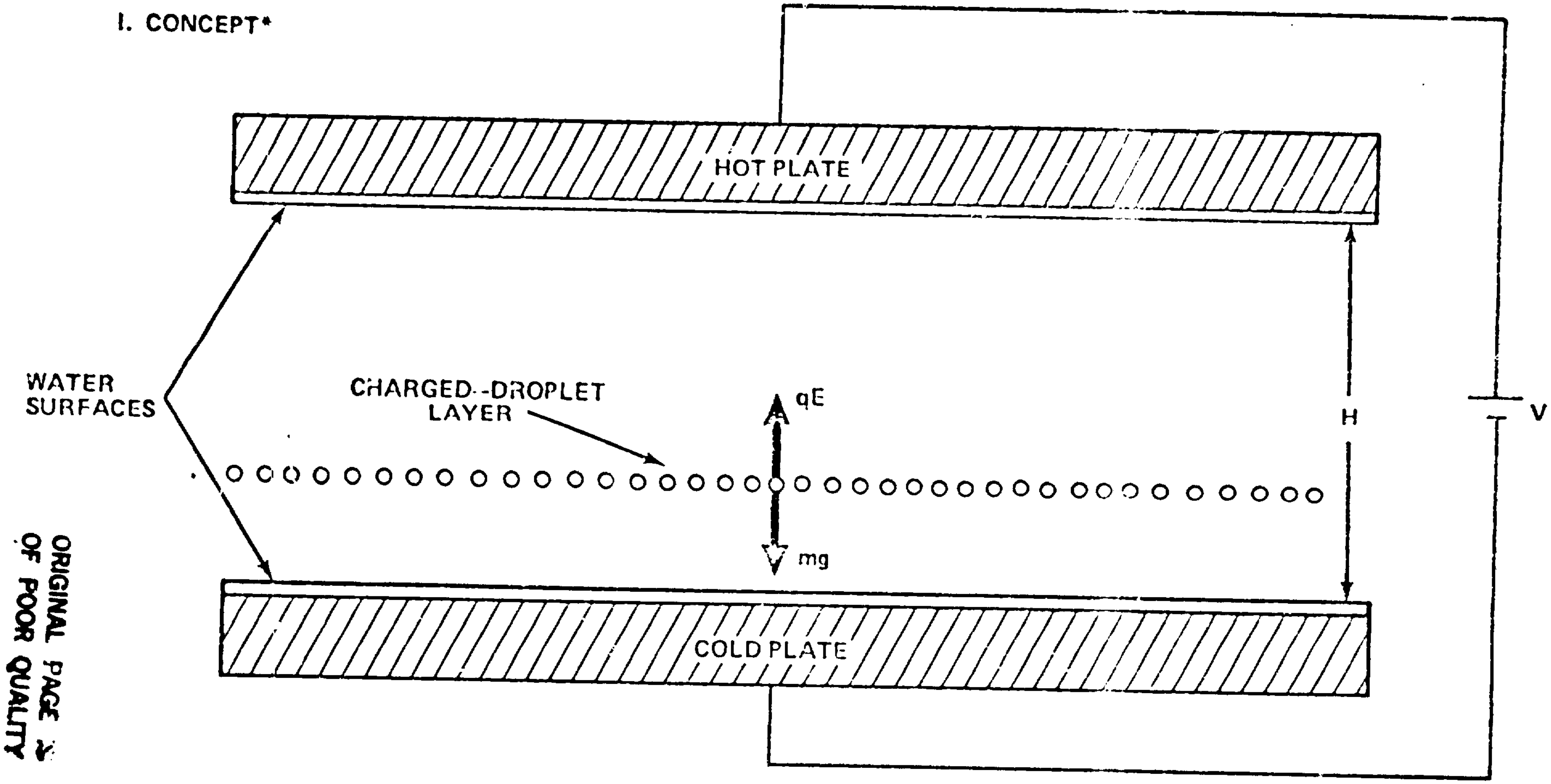
The presence of the ACPL CDR in the new quarter creates some uncertainty in the projected work list. CDR is scheduled to begin on October 9 and end on November 9. It is not yet certain how much effort will be required during CDR under this contract, outside of the known 9-17 October period. In comparison to the other tasks, this review holds a very high priority. If it is necessary to postpone or delete some of the above tasks in order to support CDR as required, Task #6 will be downgraded first, followed by Task #5.

STABLE ELECTROSTATIC LEVITATION
OF A THIN, CHARGED-DROPLET LAYER
IN A ONE-G STATIC DIFFUSION CHAMBER:

APPLICATIONS TO RESEARCH IN
CLOUD MICROPHYSICS AND LOW-GRAVITY TECHNIQUES

DAVID BOWDLE, USRA
RESEARCH ASSOCIATE

I. CONCEPT*



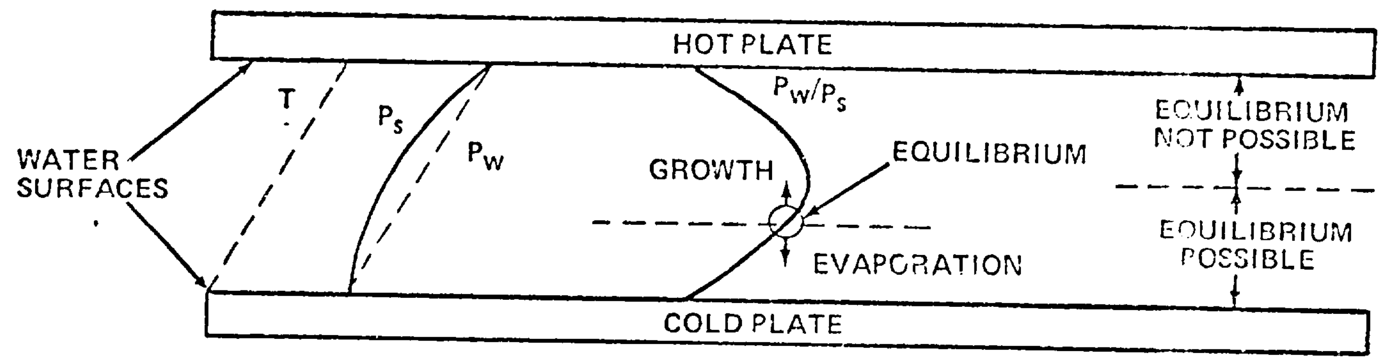
STATIC DIFFUSION (LIQUID) CHAMBER (SDL) WITH APPLIED ELECTRIC FIELD

*ADAPTED FROM – SUN, L. K., A. W. GERTLER, AND H. REISS, 1979:
"MILLIKAN 'OIL DROP' STABILIZED BY GROWTH". SCIENCE, 203, 353–354.

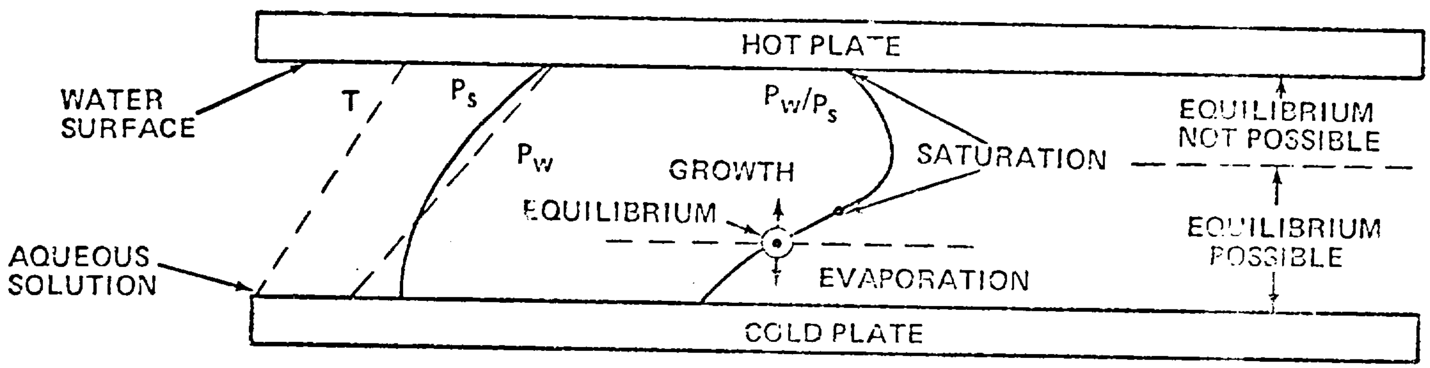
FIG 1

II. OPERATING PRINCIPLE OF STABLE LEVITATION

A. WATER VAPOR SUPERSATURATION PROFILES IN AN SDL



ORDINARY SDL, WATER ON UPPER AND LOWER PLATES



MODIFIED SDL, WATER ON UPPER PLATE, SATURATED SOLUTION ON BOTTOM PLATE.

FIG 2

II. OPERATING PRINCIPLE (CONTINUED)

B. EQUILIBRIUM WATER VAPOR SUPERSATURATION ABOVE THE SURFACE OF SOLUTION DROPLETS

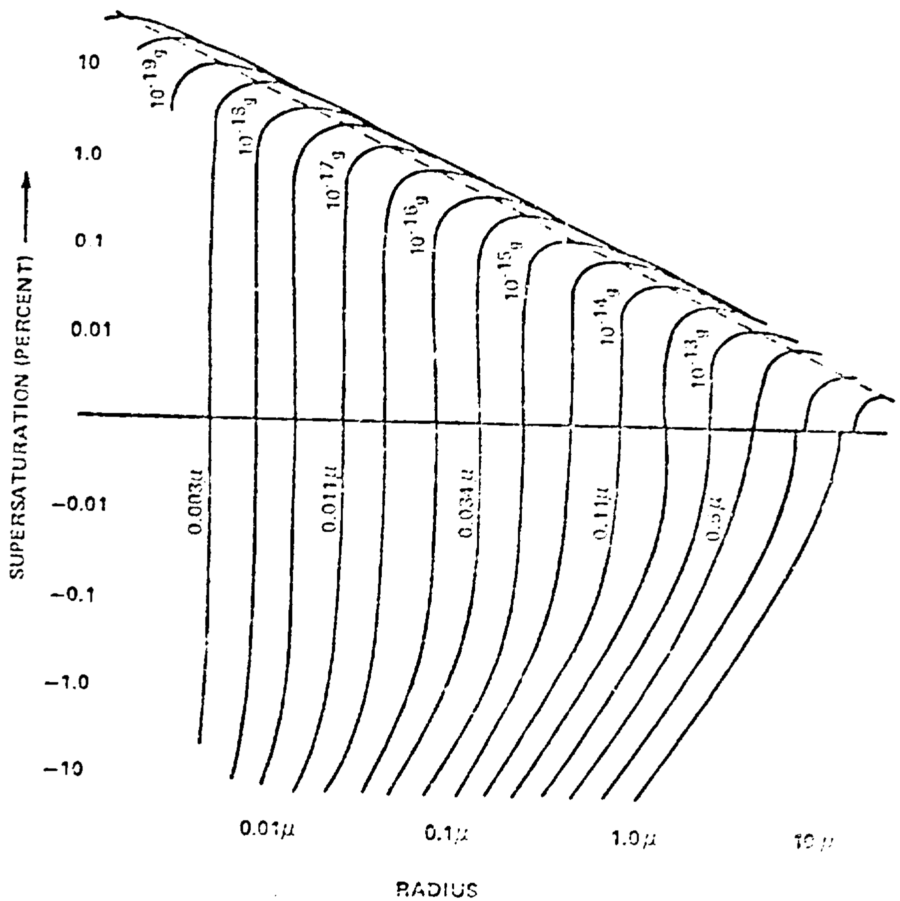


FIG. 4.7. KOHLER CURVES, RELATING EQUILIBRIUM SUPERSATURATION (OR RELATIVE HUMIDITY) TO RADIUS OF DROPLET. FOR EACH CURVE THERE IS IN SOLUTION A DIFFERENT MASS OF SOLUTE (i.e., EACH CURVE RELATES TO A PARTICULAR SIZE OF NUCLEUS, AS INDICATED ON THE INDIVIDUAL CURVES). BROKEN LINE SHOWS LOCUS OF THE MAXIMA.

FROM: TWOMEY, S., 1977: ATMOSPHERIC AEROSOLS.
ELSEVIER, NEW YORK. P. 94.

FIG 3

III. APPLICATIONS OF THE LEVITATION TECHNIQUE

A. CLOUD MICROPHYSICS

1. SCAVENGING BY HAZE, FOG, AND CLOUD DROPLETS

   PHORETIC AND BROWNIAN SCAVENGING OF PARTICLES

   SCAVENGING OF GASES

2. DROPLET CHARGING/DISCHARGING (LIGHTNING)
3. MEASUREMENT OF PHORETIC FORCES
4. VERIFICATION OF KOHLER THEORY AND NEW CCN THEORY
5. DETERMINATION OF AEROSOL SOLUBLE MASS
6. DROPLET GROWTH RATES AND ACCOMODATION COEFFICIENTS
7. NUCLEUS ACTIVATION/DEACTIVATION
8. FREEZING OF SOLUTION DROPS

B. LOW-GRAVITY TECHNIQUES

1. EVALUATE VARIOUS REMOTE DROPLET POSITIONING DEVICES IN ONE-G

   • LASER • ACOUSTIC • E-FIELD

TABLE 1

COMPARISON OF BROWNIAN AND SEDIMENTATION EFFECTS

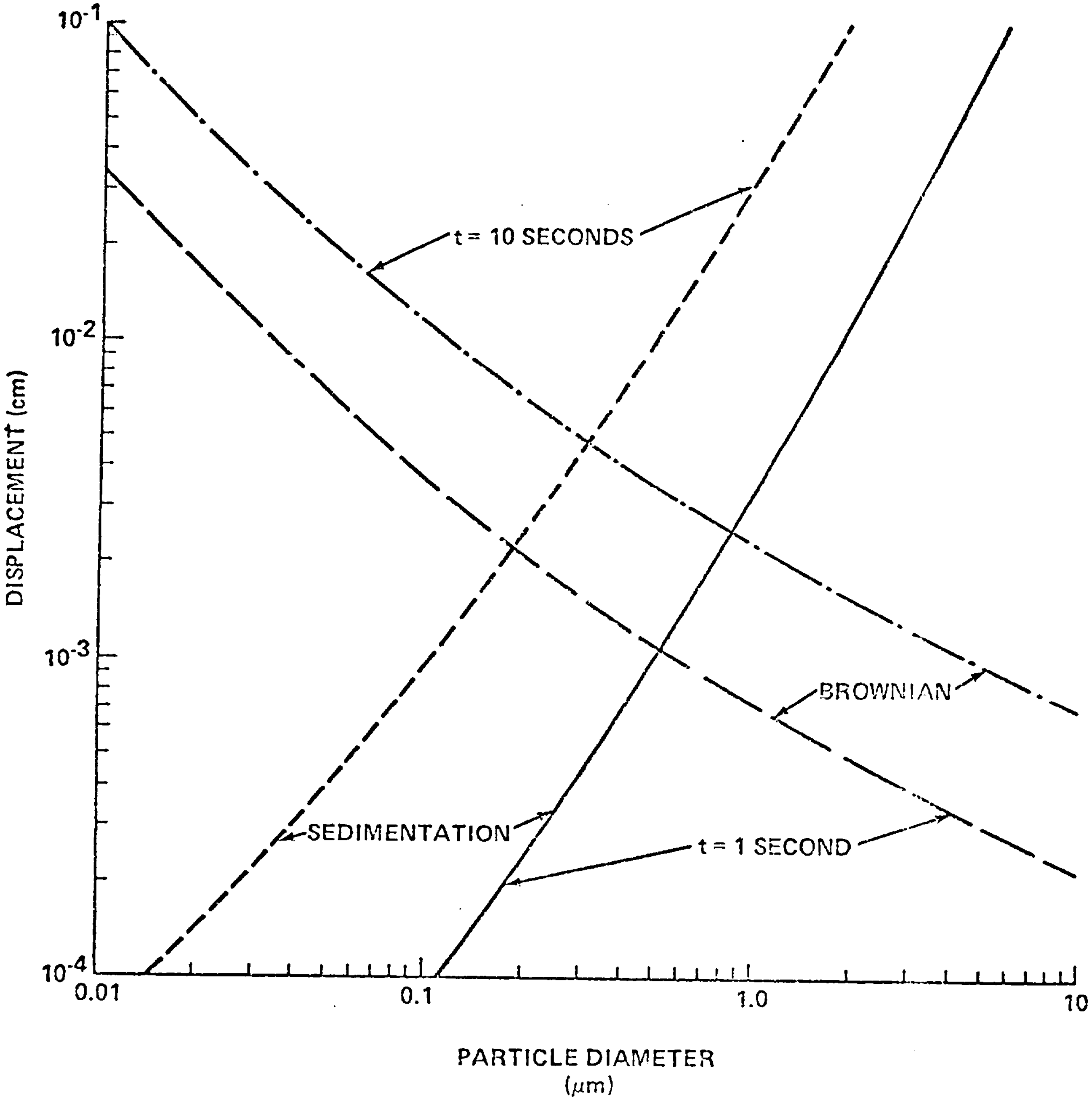


FIG 4

OPERATING PARAMETERS FOR SDL/E-FIELD LEVITATION TECHNIQUE:

SOLUTION DROPLET CRITICAL RADIUS (r_c), DROPLET RADIUS AT SATURATION (r_{100}), DRY PARTICLE RADIUS (r_d), CRITICAL SUPERSATURATION (S_c), AND SDL PLATE TEMPERATURE DIFFERENCE, ΔT (CHOSEN SO THAT $S_{MAX} = S_c$).

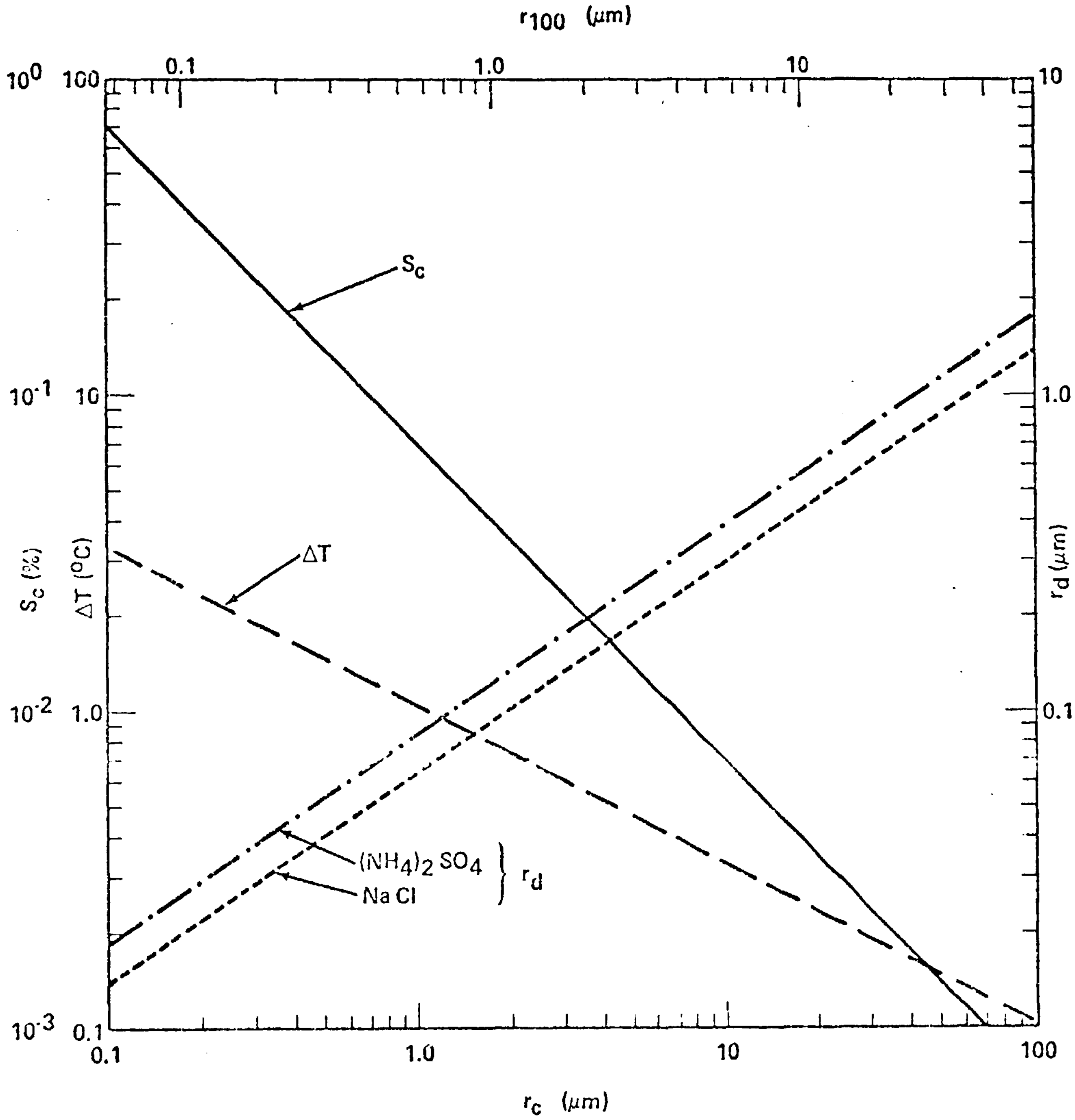


FIG 5

OPERATING RANGE OF THE LEVITATION TECHNIQUE

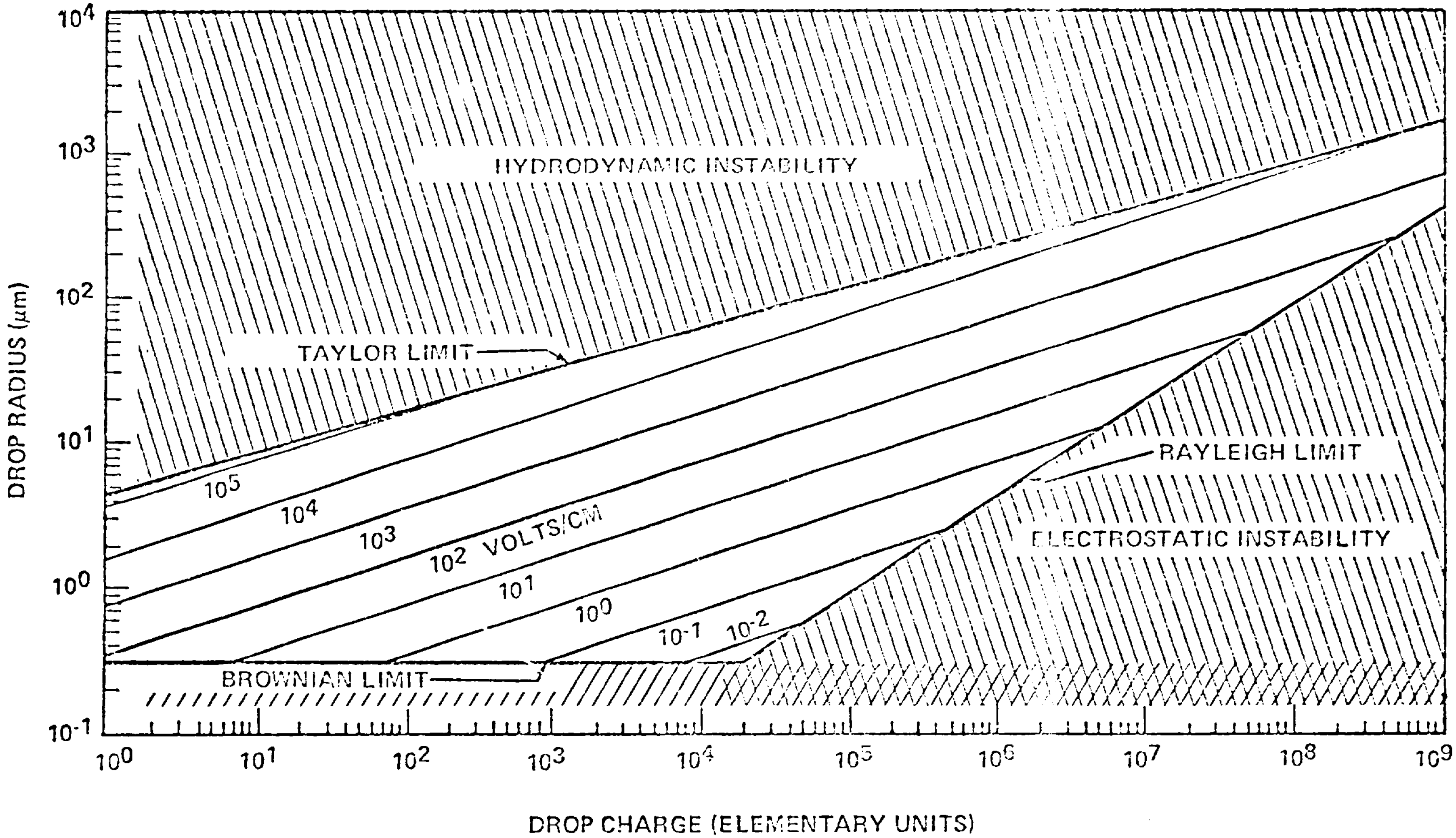


FIG 6

V. EQUILIBRIUM SENSITIVITY OF LEVITATION TECHNIQUE

A. EQUILIBRIUM RELATIONSHIPS

1. FORCE BALANCE (NEGLECT BUOYANCY, PHORETIC EFFECTS, AND BROWNIAN MOTION)

$$qE = \frac{4\pi}{3} g \rho'_{\ell} r^3$$

2. KOHLER RELATIONSHIPS (ASSUME DILUTE SOLUTION)

$$S = \frac{K}{r} - \frac{\alpha m_s}{r^3}$$

3. SDL SUPERSATURATION PROFILES (APPROXIMATE)*

$$S = \left\{\frac{Z}{H}\right\} \left\{1 - \frac{Z}{H}\right\} \left\{2.6 \times 10^{-3}\right\} \left\{\Delta T\right\}^2$$

*ORDINARY (WATER SURFACES) SDL CONFIGURATION

FIG 7

V. EQUILIBRIUM SENSITIVITY (CONTINUED)

B. EQUILIBRIUM DIFFERENTIALS

1. $$\frac{dq}{q} + \frac{dE}{E} = 3\frac{dr}{r}$$

2. $$dS = -\left\{\frac{K}{r} - \frac{3\alpha m_s}{r3}\right\}\left\{\frac{dr}{r}\right\} - \left\{\frac{\alpha m_s}{r3}\right\}\left\{\frac{dm_s}{m_s}\right\}$$

3. $$dS = 2.6 \times 10^{-3} (\Delta T)^2 \left\{1 - \frac{2Z}{H}\right\}\left\{\frac{dZ}{H}\right\}$$

COMBINING EQUATIONS 1, 2, AND 3 ABOVE GIVES THE FOLLOWING RELATIONSHIP:

$$-\left\{\frac{dq}{q} + \frac{dE}{E}\right\}\left\{\frac{K}{r} - \frac{3\alpha m_s}{r3}\right\} - \left\{\frac{3\alpha m_s}{r3}\right\}\left\{\frac{dm_s}{m_s}\right\} = 7.8 \times 10^{-3} (\Delta T)^2 \left\{1 - \frac{2Z}{H}\right\}\left\{\frac{dZ}{H}\right\}$$

FIG 8

V' EQUILIBRIUM SENSITIVITY (CONTINUED)

IT CAN EASILY BE SHOWN THAT, AT ACTIVATION, THE FOLLOWING RELATIONSHIPS WILL HOLD:

$$r_c^2 = \left\{\frac{3\ \alpha M_s}{K}\right\} \quad \text{AND} \quad S_c = \left\{\frac{4\ K^3}{27\ \alpha M_s}\right\}^{1/2}$$

HENCE,

$$r_c^3 = \left\{\frac{3\ \alpha M_s}{K}\right\}^{3/2} = (\alpha M_s)\left\{\frac{27\ \alpha M_s}{K^3}\right\}^{1/2} = \left\{\frac{2\ \alpha M_s}{S_c}\right\}$$

ALSO,

$$S_c = \left\{\frac{2\ \alpha M_s}{r_c^3}\right\} = (2.6 \times 10^{-3})\ (\Delta T)^2 \left\{\frac{Z}{H}\right\}\left\{1 - \frac{Z}{H}\right\}$$

THEREFORE

$$(\Delta T)^2 = \left\{\frac{2\ \alpha M_s}{r_c^3}\right\}\left\{\frac{1}{2.6 \times 10^{-3}}\right\}\left\{\frac{H}{Z}\right\}\left\{\frac{1}{1 - \frac{Z}{H}}\right\}$$

FIG 9

V. EQUILIBRIUM SENSITIVITY (CONTINUED)

THE EQUILIBRIUM DIFFERENTIAL CAN THEREFORE BE WRITTEN AS FOLLOWS:

$$-\left\{\frac{dq}{q} + \frac{dE}{E}\right\}\left\{\frac{K}{r} - \frac{3\,\alpha\,M_s}{r^3}\right\} - \left\{\frac{3\,\alpha\,M_s}{r^3}\right\}\left\{\frac{dM_s}{M_s}\right\} = \left\{\frac{6\,\alpha\,M_s}{r_c{}^3}\right\}\left\{\frac{1-\frac{2Z}{H}}{1-\frac{Z}{H}}\right\}\left\{\frac{dZ}{Z}\right\}$$

WHICH MAY BE REWRITTEN IN THE FOLLOWING MANNER:

$$\left\{\frac{dq}{q} + \frac{dE}{E}\right\}\left\{\left(\frac{r_c}{r}\right)^3 - \left(\frac{r_c}{r}\right)\right\} - \left\{\left(\frac{r_c}{r}\right)^3\right\}\left\{\frac{dM_s}{M_s}\right\} = 2\left\{\frac{1-\frac{2Z}{H}}{1-\frac{Z}{H}}\right\}\left\{\frac{dZ}{Z}\right\}$$

THE VALUES OF THE COEFFICIENT OF EACH DIFFERENTIAL ARE EASILY EVALUATED, AS SHOWN IN THE FOLLOWING GRAPH:

FIG 10

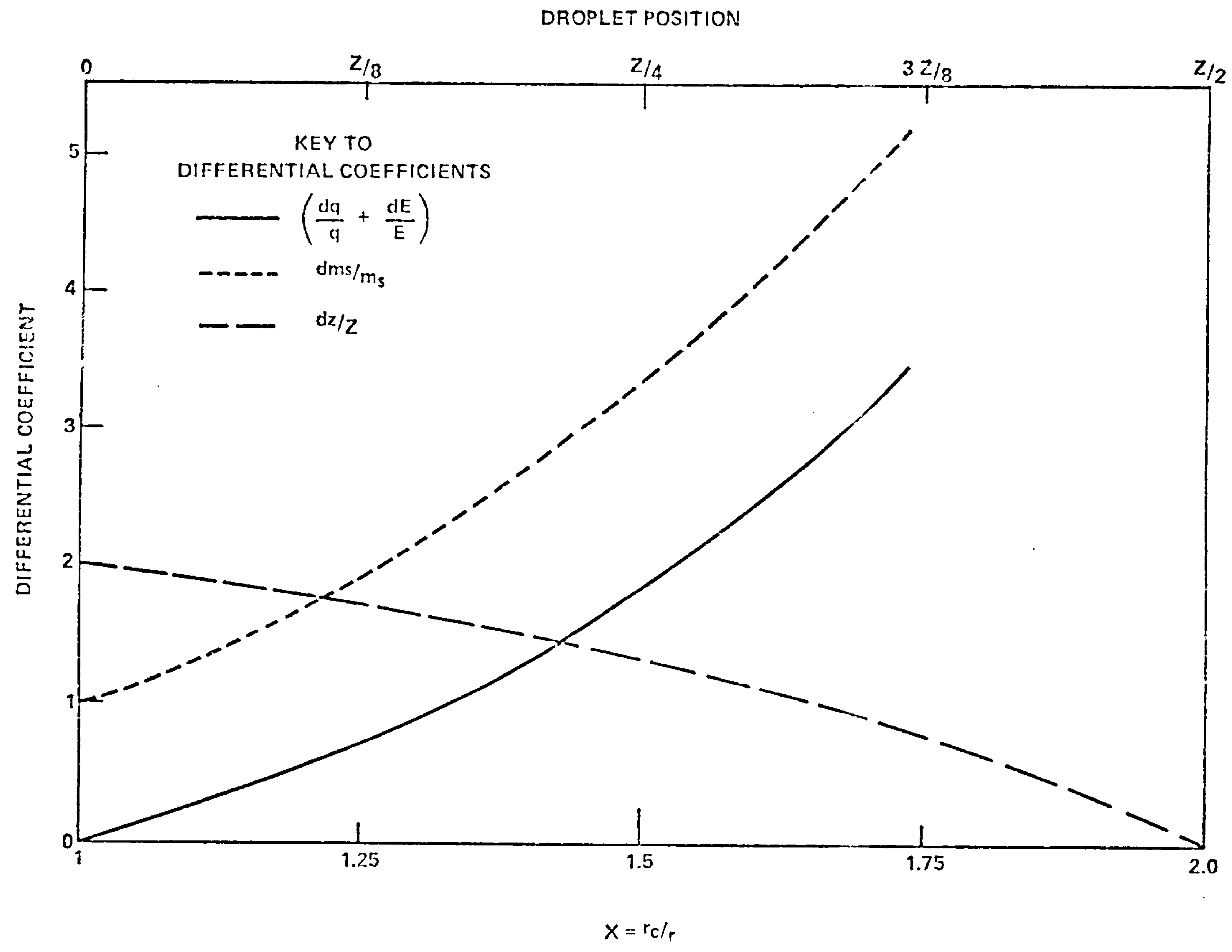

DROPLET POSITION
0
Z/8
Z/4
3 Z/8
Z/2
KEY TO
DIFFERENTIAL COEFFICIENTS
$\left(\frac{dq}{q} + \frac{dE}{E}\right)$
dm_s/m_s
dz/Z
DIFFERENTIAL COEFFICIENT
0
1
2
3
4
5
1
1.25
1.5
1.75
2.0
$X = r_c/r$

FIG 11

VI. PROPOSED DEVELOPMENT PLAN

A. FEASIBILITY STUDY

1. BUILD AND EVALUATE PROTOTYPE SDL

- $\sim$3 cm PLATE SPACING, $\sim$30 cm DIAMETER
- COMPARABLE TO DIMENSIONS OF ACPL SDL

2. EVALUATE LEVITATION TECHNIQUE FOR VARIOUS DROPLET SIZE REGIMES

- $\sim 1\ \mu m$ RADIUS (HAZE DROPLETS) $\Delta T \sim 1^{o}C$
- $\sim 10\ \mu m$ RADIUS (CLOUD/FOG DROPLETS) $\Delta T \sim 0.3^{o}C$
- $\sim 100\ \mu m$ RADIUS (DRIZZLE DROPS) $\Delta T \sim 0.1^{o}C$

3. UTILIZE PROTOTYPE SDL AS NEEDED FOR EVALUATING VARIOUS LOW-GRAVITY DROPLET "HANDLING" TECHNIQUES

TABLE 2