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INSTITUTE for FLUID DYNAMICS and APPLIED MATHEMATICS

Technical Note BN-711

August 1971

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FACILITY FORM 602

<u>N71-38548</u> (ACCESSION NUMBER)	<u>B3</u> (THRU)
<u>17</u> (PAGES)	<u>none</u> (CODE)
<u>CRA123119</u> (NASA C OR TMX OR AD NUMBER)	<u>29</u> (CATEGORY)

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* Research supported by NASA Grant ~~NSG~~ 21-002-311, and computer time provided by Computer Science Center of the University of Maryland.

Abstract

Examination of separately determined Helium and Hydrogen bulk speeds in the solar wind show these to be equal, both on time scales of 30 minutes and 3 minutes. Observations of two interplanetary shocks and 12 discontinuities show the changes in bulk speed across them to take place simultaneously for the two species. Observations made at times of high Helium abundance following an interplanetary shock, and at times of observation of colliding streams in the plasma, confirm the conclusion that, if bulk speed differences between species occur, they do so very rarely.

Introduction

This paper concerns an examination of the bulk speeds of helium and hydrogen in the solar wind.

Recent work (Ogilvie and Wilkerson, 1969; Robbins, Hundhausen and Bame, 1970; Formisano, et al., 1970) has shown that the solar wind contains a variable proportion of helium ions. These ions are generally believed to travel with the predominant species (protons) at the same bulk speed of between 300 and 700 km sec⁻¹. This statement is largely based upon observations with electrostatic analyzers, where there exists a difficulty in principle in resolving the two species. A helium ion travelling at the same bulk speed has an energy per unit charge twice that of a proton. For a considerable fraction of the time the random speeds in the frame of reference moving with the plasma are large enough for the two energy per unit charge distributions to overlap appreciably, and they must be separated. Numerical data reduction techniques used for this purpose may lead to erroneously low values for the helium bulk speed due to this uncertainty in separating the energy per unit charge distributions of the two ions. This situation is most serious when the differential velocity intervals in which the observations are made are widely spaced.

The GSFC-University of Maryland plasma instrument (Ogilvie and Wilkerson, 1968), which formed part of the experiment complements of the satellites Explorers 34 and 41, separated helium from hydrogen ions using both energy per unit charge and velocity analysis, and

data from this experiment are free from this possible problem. It is generally accepted that the bulk speeds U_p and U_α are at least on the average equal, as shown by Robbins, et al. (1970), and by an early investigation using a limited amount of the present data (Ogilvie, Burlaga and Wilkerson, 1968). We now extend this work, using all the appropriate data acquired by Explorer 34, to obtain a much more definite result.

Egidi, et al. (1970) have suggested that there are periods of time, long compared with that required to make a measurement (3 minutes in our case) during which there is a sustained difference between the bulk speeds of the hydrogen and the helium. They also claim that discontinuous changes in the bulk speed of one ion species occur without corresponding changes in that of the other. We shall investigate these questions below, and show that our evidence does not support either claim.

Theoretical Background

Measurements of different values for U_α and U_p over an appreciable period of time, such as those reported by Egidi, et al. (1970) and Formisano, et al. (1970), imply either that forces are acting to render the bulk speeds unequal, or that the two ionic species were not accelerated to equal speeds in the solar corona, and that plasma instabilities did not act subsequently to equalize them. It is possible that relative motion between the protons and other ions in the solar wind could give rise to two-stream instabilities which might destroy that motion. The extent to which

the helium content of the solar wind affects the conditions for ion wave instabilities to occur has previously been investigated theoretically by Fredericks and Scarf (1965). They showed that helium ions must travel more slowly than protons to lower the critical drift speed for marginal stability, but that this effect is negligible for experimentally observed concentrations, so that in the solar wind the helium has no effect upon the critical drift speed required to excite these instabilities. If T_e and T_p are the electron and proton temperatures respectively, the marginal stability condition without addition of helium for $T_e/T_p = 5.0$, a high value for the interplanetary medium, requires the critical electron-proton drift speed to be greater than 360 km sec^{-1} , (Bernstein et al., 1964). In fact the Helium-Hydrogen drift speed might be expected to be limited to the Alfvén speed ($30\text{-}100 \text{ km sec}^{-1}$) by other processes. Since it seems possible that a large relative drift speed of either sign might persist for macroscopic times, it is worthwhile to examine critically the present data. The difference in direction of flow which would generally accompany a flow speed difference cannot be detected by the instrument.

In Figure 1 we show a histogram of the ratio T_α/T_p , where T_α is the helium temperature obtained from data set A (described below). The average ratio is seen to be 3.0, indicating that the two species of ions do not usually have the same temperature, but rather tend to have the same velocity distribution ($T_\alpha/T_p = 4.0$). This is in agreement with the results of other workers and indicates that some wave-particle interactions between the species do occur.

Thus we do not expect to find bulk speed differences on the average, but identification of some periods characterized by such differences would be of great interest for the study of instabilities in the interplanetary plasma.

Data Analysis

In the present study, observations were made at 3-minute intervals, but the Helium counting rate did not always exceed the instrumental threshold.

One data set, A, consists of averages formed from the individual helium counting rates over a period of 30 minutes. Averaging improves the signal to noise ratio and thus makes better use of data from periods of time when the proportion of helium to hydrogen was low. The curve fitting procedure used to obtain density n , bulk speed U and temperature T , was described in Ogilvie, Burlaga and Richardson (1967). This method applied to averaged data tends to give anomalously high temperatures, since the temperature is sensitive to shifts in bulk speed and the helium-hydrogen temperature ratio. The fitting procedure requires nonzero counting rates in at least two differential velocity intervals and is the same as that used to obtain the bulk speed characterizing the protons.

For another data set, B, consisting of 1583 individual measurements the bulk speeds are studied using an improvement in the procedure outlined in Ogilvie and Wilkerson (1969). Here for each spectrum we assume a Maxwellian velocity distribution,

normalized to the largest count characterizing any velocity interval, and two alternative assumptions, $T_{\alpha} = T_p$ and $T_{\alpha} = 4T_p$ are made. Calculations of the expected counting rates at the adjacent velocity intervals are then made for $U_{\alpha} = U_p$, $U_{\alpha} = U_p \pm 3.5\%$. If one of these six alternatives predicts counting rates within a given percentage deviation from the observed values for the velocity intervals adjacent to that showing the largest count, this is called a fit. A few cases indicate a fit for two alternatives; the one with the lowest deviation is then taken.

Thus set A indicates bulk speed differences between the species on a 1/2 hour time scale. Set B indicates what proportion of individual measurements are consistent with $U_p = U_{\alpha} \pm 3.5\%$, and by the examination of "no fit" cases, directs attention to possible short periods when $|U_p - U_{\alpha}| > 3.5\%$.

The data has been examined to see if

- (a) the average bulk speed difference derived from data set A is close to zero, in agreement with the findings of Robbins et al. (1970).
- (b) the bulk speed difference values for data set A are normally distributed.
- (c) the standard deviation we derive from data set A is consistent with the measurement error, estimated in other ways.
- (d) there are any velocity differences greater than 10%.
- (e) using the data set B, there are shorter periods of consistent differences in bulk speed.

(f) there are abrupt changes in the bulk speed of one species without a corresponding change in that of the other species.

Results

Figure 2 shows a histogram of the number of observations plotted against U_{α}/U_p , taken from data set A, the 30-minute averages. The distribution is centered on zero, and is a good fit to the normal distribution with the same total area, also shown; it contains 637 cases. The calculated standard deviation, assuming a normal distribution, is shown and has the value 0.03. This standard deviation corresponds well with the expected measurement error of a few percent for each bulk speed measured separately. The speed interval between adjacent differential channels for the Explorer 34 experiment was approximately 10% and their width was 4.5%. Thus, when an appreciable counting rate is seen in only one channel, the error in speed determination might be as large as 5%, but the observation of nonzero rates in more channels improves this figure rapidly.

To a second order, the observed distribution differs from the normal distribution in having more values close to zero, and there are no cases where U_{α} differs by more than 11% from U_p in either direction. In preparing Figure 2, we eliminated 5 cases where such differences were apparently present. In each case this was found to be due to noisy data, etc., and no data was eliminated without careful scrutiny of the corresponding individual readings which made up the average. We thus find no evidence for systematic bulk speed

differences as large as 11 percent which persist for as long as 30 minutes.

A possible objection to this conclusion is that the presence of the background causes the elimination of periods of low helium concentration and simultaneous low hydrogen density, which might favor the presence of large bulk speed differences. This criticism could only apply for proton densities less than about 5 cc^{-1} and simultaneous proportions of helium less than average (0.04%). The data shows no evidence of the onset of such an effect, as one goes from high to low densities. The observation in data set B was used to examine the possibility of the existence of shorter periods of sustained bulk speed difference; none were found.

All the apparent cases were eliminated as being caused by artifacts of one kind or another. Among these is the effect of bulk speed changes during the taking of the sequential observations which make up an energy-per-unit-charge spectrum. This must occur occasionally, and produces unusual, but characteristic changes, which might be misinterpreted.

An examination of the data from set B for abrupt changes in bulk speed of one species, without a corresponding change in that of the other, also yielded a negative result. In particular, we examined 14 velocity discontinuities and 2 shocks for evidence of this effect. This subset of the observed shocks and discontinuities occurred at times when the helium was observable both before and after the discontinuity. Observed bulk speed charges for the shocks are seen in Table I below, which gives an idea of the accuracy of the speed determination; the discontinuity observations have similar accuracy.

TABLE I

Date	Time	U_{p1}	U_{p2}	ΔU_p	$U_{\alpha 1}$	$U_{\alpha 2}$	ΔU_{α}
1967	U.T.	km sec ⁻¹					
25 June	0215	295±3	326±3	31±5	296±8	325±8	29±11
26 June	1455	416±5	448±5	32±7	410±15	455±15	45±21

Time between measurement of ΔU_p and ΔU_{α} is 3 min.

This shows that $\Delta U_p = \Delta U_{\alpha}$ for each shock, and that sustained differences greater than about 15 km sec⁻¹ are ruled out; note this is less than the Alfvén speed. The same conclusion is true for the twelve velocity discontinuities, to the same order of accuracy. Of course, this observation does not rule out the possibility that bulk speed differences due to the differences in the inertia of the ions will become observable when time resolution is improved.

In Figure 3a we see a histogram of data taken when the plasma in the region of the satellite was in collision with a faster moving stream from a solar active region. This event is one of three described by Burlaga et al. (1970). Again there is no evidence of any difference between the bulk speed of the hydrogen and helium, although such a situation might be expected to be a favorable one for observation of a bulk speed difference.

Figure 3b shows histograms for two sets of observations made at times when the relative abundance of helium was abnormally large, following an interplanetary shock. Although the maxima of the individual sets of readings peak at +10 km sec⁻¹ and -10 km sec⁻¹, it is clear that there is no significant difference between these observations

and that both sets are consistent with zero relative speed for the species.

We conclude that our data are consistent with equality between the bulk speeds of the hydrogen and helium ions under all the conditions examined, and that they provide no evidence of inequality over times as long as a few minutes to the accuracy indicated above. If the bulk speeds remain unequal for macroscopic time intervals, this effect must be rare enough not to have been seen in a sample of hundreds of hours of observation of a wide variety of conditions.

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Figure Captions

- Figure 1 The distribution of the ratio of the Helium and Hydrogen temperatures for the 30-minute averages in data set A. The most probable value is $\sim 3 \pm 1$.
- Figure 2 The distribution of values of U_{α}/U_p for the 30-minute averages of data set A. This is discussed in the text.
- Figure 3a Distribution of bulk speed differences during a colliding stream event on July 17, 1967 (3-minute intervals).
- Figure 3b Distribution of bulk speed differences during high helium content periods on May 30 and June 8, 1967 (3-minute intervals).





