tions. The liquid surface is therefore estimated to be about 150°C by this independent method.

The conduction electrons in the liquid at the arc spot are at a temperature of 4000°K according to this emission theory. The observations indicate they emit light as an incandescent body. The atomic constituent of the excited region is at approximately 150°C. If these things be true, then the cooling of the liquid by evaporation and by ordinary thermal conduction along the atomic constituent plus losses due to convection are together able to keep pace with the energy transfer from the excited electronic medium over to the atomic matrix. This rate of transfer is expected to be low but no attempt at a theoretical estimation of it will be made at this time.

For the sake of clarity, however, we recall in this connection the well-known fact that sputtering of a cathode is readily produced by bombardment with masses of atomic magnitude, namely, ions; whereas the plate of a radio tube bombarded by electrons suffers little or no sputtering. Evidently the transfer of energy to the atomic lattice is direct in the ionic case but indirect in the electronic. Where the mass of colliding particle and target particle are nearly equal the efficiency of direct energy transfer would be considered greatest. The electronic bombardment must heat electrons in the metal first and these in turn transfer energy to the atoms.

The emission theory, therefore, seems to introduce ideas in harmony with those previously acceptable. It fits in with known factors in the vapor above the arc spot. It seems to be the only theory compatible with the characteristic behavior of the arc spot in a transverse magnetic field and the extinction phenomena cited, and leading to an explanation of the characteristic current density. The lack of equilibrium between the hot electronic medium and the relatively cool atomic matrix involves an account that can possibly be elaborated upon later.

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The Loss of Energy of Hydrogen Ions in Traversing Various Gases

CRAIG M. CRENSHAW
Department of Physics, New York University, New York

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The loss of energy of hydrogen and deuterium ions having initial energies in the range from 60 to 340 kev has been measured as a function of their path in various gases at various pressures. The measurements are expressible in terms of the energy loss in kev per cm of path per mm of pressure as well as in terms of stopping power relative to air. The gases examined are air, water vapor, hydrogen, deuterium, and helium.

APPARATUS

Figure 1 shows the general plan of the apparatus. The hydrogen or deuterium ions after being accelerated by means of a Cockcroft-Walton voltage quadrupler pass into the field of the resolving magnet. Here a mass beam is selected and properly deflected so as to pass on through the gas absorption chamber. After traversing the gas the beam is again brought into a high vacuum and passed through the field of a measuring magnet. This magnet is so adjusted as always to bend the beam a definite amount as determined by the ion beam fluorescence on the observation screen. Thus the magnetic field of the measuring magnet measures the energy of the ions after passing through the gas.

Figure 2 gives a detailed sketch of the absorption chamber. The gas is confined by means of a fine capillary system of diaphragms at each end of the chamber. The gas which does escape through these capillaries is removed by a liquid air trap and a system of high speed pumps.

Several features in the design and operation of the apparatus have been given special attention. Energy measurements are all made in terms of a carefully constructed and calibrated resistance voltmeter. The energy of the exit beam as given by the magnetic field of the measuring magnet depends for its conversion into kev upon calibrations made with no gas in the absorption chamber. Under such conditions the exit beam has the same energy as the known incident beam.

The beam is brought in and out of the gas absorption chamber through the capillary systems. There it encounters pressure gradients. The upper capillary system is movable and these end effects are evaluated by taking data for a second position. Pressure in the various parts of the system has been carefully watched with suitable gauges. The pressure in the absorption chamber is accurately measured with an oil manometer.

Arrangements are such that the position of the high energy edge of the spot on the viewing screen is relatively insensitive to adjustments of the analyzing magnet and minor adjustments of the beam. A slight shift changes only the portion of the beam used in the finer apertures of the absorption chamber. Thus a correspondence between the most energetic particles in the incident and exit beam is a real one and repeatable.

The field strength of the measuring magnet is measured by a ballistic galvanometer and a flip coil. The galvanometer throw is read three times. If these readings do not agree with 0.04 cm on a fifty-centimeter scale, the throws are repeated until consistent results are obtained. The galvanometer series resistor is adjusted to give a fifty-centimeter throw for the fastest ions measured.

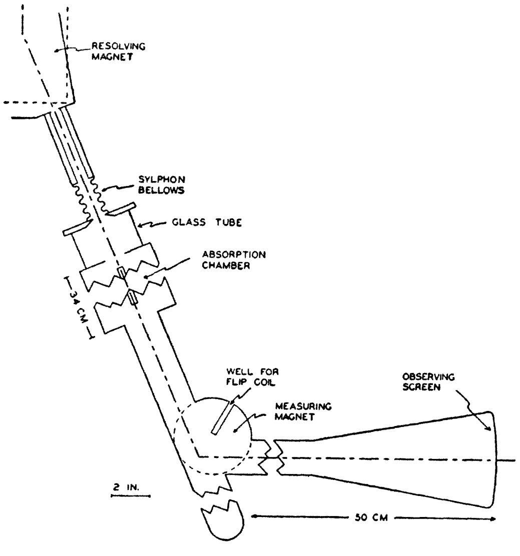

FIG. 1. General plan of the apparatus.

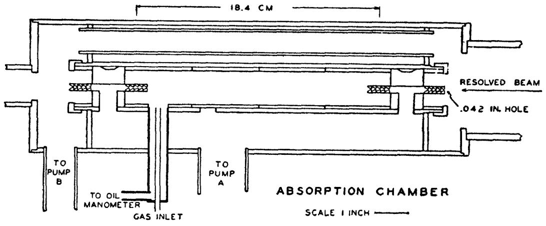

FIG. 2. The absorption chamber showing the pumping and pressure connections.

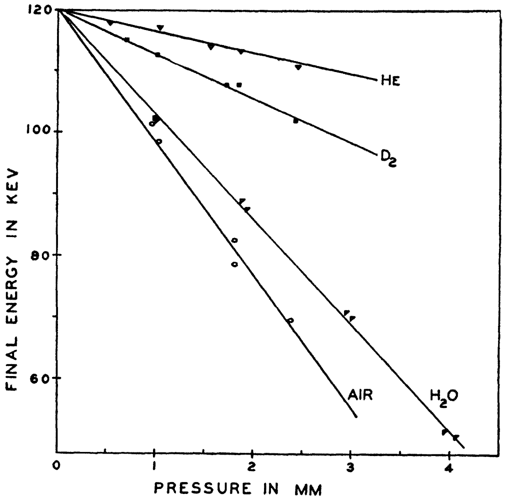

FIG. 3. Energy of the exit beam as a function of pressure in the absorption chamber.

DISCUSSION OF DATA

Tests have been run first to determine the linearity of the loss of energy with respect to the pressure of the absorbing gas. Figure 3 is a sample plot of such data. These measurements, repeated at forty-kilovolt intervals throughout the whole range, show in general that the relation between loss of energy and pressure is linear. A slight departure from linearity is to be expected for large pressures if the loss of energy depends upon the incident energy. For water vapor at a pressure of 5 mm, this deviation from linearity

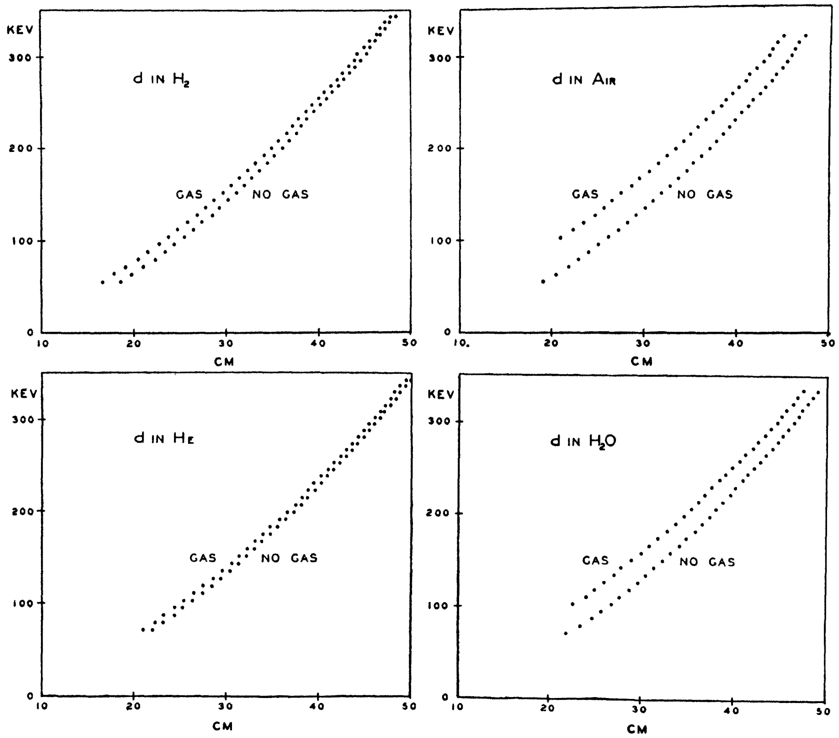

FIG. 4. Incident energy of deuterons as a function of galvanometer deflection for four gases.

is observed in the range where the energy loss is dependent on the incident energy.

To evaluate the energy dependence of the energy losses and to get the most accurate measurements of the magnitude of the loss of energy, data like those shown in Fig. 4 have been taken. It was found that gross changes in the focusing properties of the accelerator tube did affect the energy calibration of the measuring magnet. To overcome this difficulty calibration data were taken concurrently with the energy loss data.

First the field of the measuring magnet is adjusted so that the beam strikes the screen at the fiducial mark with no gas in the absorption chamber. This field strength is then measured by the flip coil and galvanometer. Next gas is admitted to the absorption chamber until the pressure is 2 mm and the field of the measuring magnet is readjusted and measured. This process is repeated in steps of about eight kilovolts throughout the whole available range from 60 to 340 kilovolts. Any disturbance that might affect the galvanometer reading or the beam position will then influence both the observation curve and the calibration curve in the same manner. If some adjustment has to be made, such as the shifting of the galvanometer zero or refocusing the beam, then by repeating the last point after the adjustment the points can be shifted to agree at this value. Since the

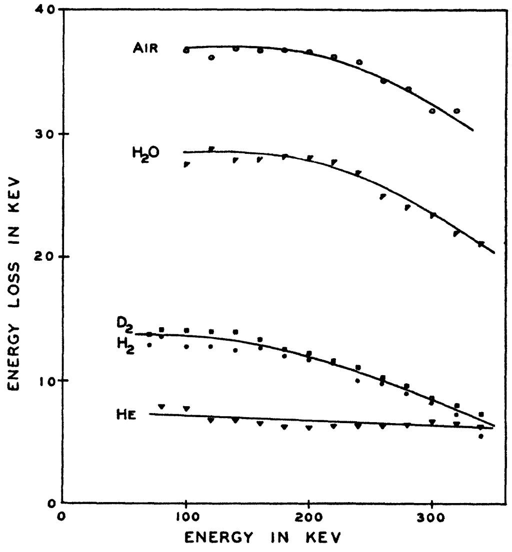

FIG. 5. Loss of energy of deuterons in kev for 18.4-cm path at 2-mm pressure in various gases as a function of incident energy.

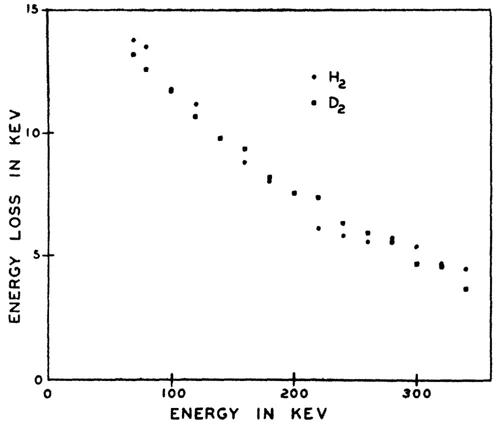

FIG. 6. Loss of energy of protons in kev for 18.4-cm path at 2-mm pressure in H_2 and D_2 as a function of incident energy.

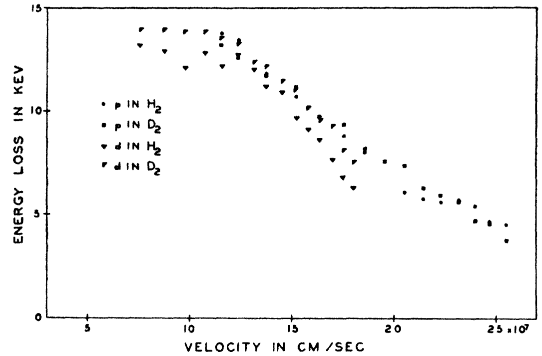

FIG. 7. Loss of energy of protons and deuterons in kev for 18.4-cm path at 2-mm pressure as a function of velocity.

resulting curve always joins smoothly, this shifting is justifiable.

These values are plotted as indicated in Fig. 4. The ordinate is the energy of the particles as they enter the absorbing chamber as measured by the voltmeter. The field strength of the measuring magnet is expressed in terms of the galvanometer deflection of the flip circuit. This deflection is plotted as abscissa. When there is no gas in the chamber, the emergent and incident energies are the same. Thus the curve obtained with no gas, shown on the right in each plot, is a calibration curve showing the energy of the particle corresponding to any galvanometer deflection. In the curve obtained with gas in the absorption chamber, the galvanometer deflection is that corresponding to the energy of the emergent beam. Points on the two

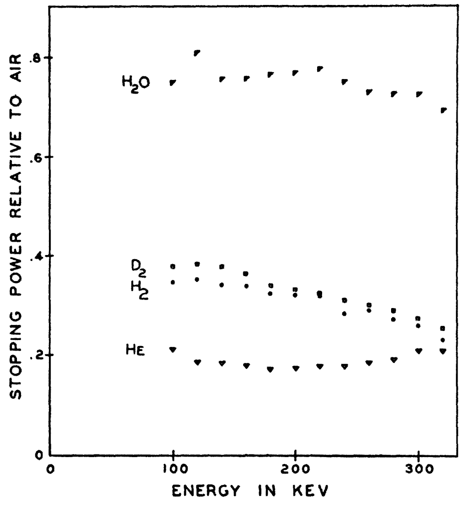

FIG. 8. Stopping power relative to air for various gases as a function of incident energy.

curves having the same abscissa have thus the same energy for the emergent particles. This energy is shown by the ordinate of the point on the curve with no gas. The incident energy is the ordinate of the point on the curve with gas, and the loss of energy is the difference of the ordinates of the two points.

Figures 5 and 6 show plots of the loss of energy in various gases as a function of incident energy. Values for the ordinate were obtained from large scale plots of the observed data. A least squares analysis was also made for some of the data and yielded almost identical results. The difference in the loss of energy in the hydrogen isotope gases is of the same order of magnitude as the accuracy of the observations. This is contrary to preliminary measurements reported in an abstract.

The loss of energy of protons and deuterons of the same velocity is shown in Fig. 7. The values agree sufficiently well to indicate that no difference exists between the isotopic projectiles.

Figure 8 shows stopping powers relative to air.

ACKNOWLEDGMENTS

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[1] C. M. Crenshaw, V. J. Young, H. P. Manning, Phys. Rev. **61**, 388A (1942).