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DIFFUSION OF PLASMA ACROSS A MAGNETIC FIELD

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(Received February 10, 1961)

The diffusion of plasma across a magnetic field has been the subject of several calculations.[1-4] However, all these assume local thermal equilibrium (i.e., the zero-order distribution is Maxwellian), although in some cases the ions and electrons may have different temperatures. These calculations all lead to a diffusion proportional to $1/B^2$. Bohm[5] suggested that there might be a form of diffusion in which fluctuating electric fields are present and produce a diffusion proportional to $1/B$. In the course of work on the application of fluctuation theory to transport problems in plasma,[6] a derivation of diffusion has been found which encompasses both classical and Bohm diffusion and indicates that, when suitably expressed, the Bohm formula gives the maximum value which the transverse diffusion can ever attain.

We consider a situation in which a density gradient exists in one direction only, perpendicular to $\vec{B}$, and where the magnetic pressure is dominant. The ion velocity will generally be much less than electron velocities so that the mean drag (dynamic friction) on an ion will be proportional to the ion velocity. Then we can write the Langevin equations for motion transverse to the magnetic field as

$$\dot{u} = -\beta u + \omega v + X,$$
$$\dot{v} = -\beta v - \omega u + Y, \tag{1}$$

where $M\beta$ is the coefficient of dynamic friction, $\omega = eB/Mc$, and MX/e, MY/e are the fluctuating electric field components. These fluctuations are assumed to be statistically independent of u, v and to have a stationary distribution.

The solution of these equations can be written

$$u(t) = e^{-\beta t}(u_0 \cos\omega t + v_0 \sin\omega t) + \int_0^t e^{\beta(s-t)}[X(s)\cos\omega(s-t) - Y(s)\sin\omega(s-t)]ds. \tag{2}$$

Then, the mean square displacement per unit time is

$$\langle\Delta x^2\rangle = \frac{1}{T}\int_0^T\int_0^T \langle u(t)u(t')\rangle dt\,dt',$$

which for T greater than a typical fluctuation time becomes

$$\langle\Delta x^2\rangle = 2\int_0^T \langle u_0 u(\tau)\rangle_0 d\tau. \tag{3}$$

Evaluating the correlation coefficient from (2) and using the statistical independence of u_0, v_0, X, Y, one finds

$$\langle\Delta x^2\rangle = 2\langle u_0^2\rangle\beta/(\beta^2+\omega^2). \tag{4}$$

Recalling that the contribution to the flux arising from $\langle\Delta x^2\rangle$ is

$$F_2 = -\tfrac{1}{2}\frac{\partial}{\partial x}[\langle\Delta x^2\rangle n(x)],$$

we see that $\langle\Delta x^2\rangle$ is essentially the diffusion coefficient. It can be verified that if we ascribe to β the conventional value [1,6] for a Maxwellian distribution, then we recover the classical flux,[2] which for large magnetic fields is

$$F_c = -\tfrac{4}{3}\left(\frac{2\pi mc^2}{kT}\right)^{1/2}\frac{e^2c}{B^2}\frac{\partial}{\partial x}[n^2(x)]. \qquad (5)$$

However, the interesting feature of (4) is that, while β will depend on the electron distribution, no matter what value β may in fact take, $\langle\Delta x^2\rangle$ cannot exceed

$$\langle\Delta x^2\rangle_m = \langle u_0^2\rangle/\omega = \tfrac{2}{3}cW/eB, \qquad (6)$$

where W is the mean ion energy.

It will be recognized that, apart from a numerical factor, (6) leads to the value of diffusion suggested by Bohm, the value given by (6) being

$$F = -\tfrac{1}{4}(c/eB)(\partial p/\partial x),$$

where we have taken p, the total pressure, to be twice the ion pressure. One concludes, therefore, that this diffusion is the maximum that can be attained with ions of a specified mean energy in a magnetic field of value B.

It will be noted that we have not considered the effect of the first-order moment $\langle\Delta x\rangle$, which cannot easily be obtained from (1) since it depends on variations in β. However, it can be demonstrated that, provided the mean ion and electron energies are equal, the first-order contribution vanishes for ions of $Z = 1$.

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CRYSTAL STRUCTURE OF THE β FORM OF He^4†

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(Received February 13, 1961)

In 1953 Dugdale and Simon[1] reported that upon investigating the thermal properties of solid He^4 they observed a first order transition whose equilibrium line cuts the melting curve at 14.9°K. The nature of the transition indicated a change in crystal structure. Since the calculated entropy and volume change associated with the transition were very small, they assumed that on crossing the equilibrium line from the low-temperature side the structure changed from the already known hexagonal closest packing, α-phase, to cubic closest packing, β-phase. Whether helium solidifies in the cubic closest packed structure as the other inert gases do has been of theoretical interest. Barron and Domb[2] from theoretical considerations have shown that one might expect a transition to the cubic form to occur in solid He^4 at an elevated temperature. We have therefore investigated by x-ray diffraction the structure of the new phase discovered by Dugdale and Simon.

The cryostat and camera arrangement previously used[3,4] for crystal structure studies at low temperatures was modified to permit oscillation photographs to be taken. This was done by replacing the cylindrical Dewar by another which had the cross section of an annulus, thus permitting a shaft to be inserted down the geometric center of the Dewar. The upper end of the shaft projected through the top of the cryostat case where it connected to a cam and follower arrangement for oscillating it. As shown in Fig. 1, at the bottom of the shaft a beryllium cell was attached into which the helium was solidified. The cell had a 0.8-mm bore and a 0.4-mm wall. The open end of the cell was connected to the filling tube by a compression closure which consisted of a 59-degree cone tightened into a 60-degree seat with a brass gland nut. The differential in thermal contraction between brass and beryllium is such as to cause the joint to become tighter with lower temperature. The cell was cooled by the bath of liquid hydrogen through three braided copper straps. These and the filling and thermometer capillaries were attached with sufficient flexibility to allow the shaft to oscillate through an angle of 30 degrees. Not shown in Fig. 1 is the liquid-nitrogen-cooled copper radiation shield