LETTERS TO THE EDITORS

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The Magnetic Current

IN an article in *Nature* of February 5, 1944, entitled "Magnetic Current", Mr. James T. Kendall deals with movements of dia- or para-magnetic liquids in non-homogeneous magnetic fields, combined with electrodynamic rotations. He states that his horizontal magnetic field is not uniform (non-homogeneous) and observes the mass movement of the liquid as disclosed by refractive index striation without making use of the dark field of a microscope.

I am using vertical magnetic and electric fields of the highest homogeneity, separately and combined, so as to make those fields coincide with the gravitational field[1]. The two vertical cylindrical pole pieces, 6–12 mm. in diameter, have been adjusted so that their opposing circular faces are exactly horizontal and parallel, and the distance separating them can be regulated. In and around the space between these two pole faces (0·5–2 mm. apart) the movement of single microscopic particles in gases or particles and bubbles in liquids can be observed in the dark field of a microscope with low or high aperture. It is self-evident that observation with more sensitive means discloses new facts, permitting measurements of forces down to 8×10^{-11} dynes. Those forces are measured by comparing them with the gravitational force exerted upon the single particle[2,12].

The essential facts proving the existence of the magnetic current are the following. (1) Polar movement of single particles to the north or to the south in a homogeneous magnetic field in gases, reversing their direction with the reversal of the field, their velocity depending on the field strength. The Peregrinus experiment of A.D. 1269 leads to a positive result when repeated with sensitive means. The above observation[3] leads to the concept of the magnetic ion, counterpart to the electric ion. Magnetic ions, north or south, can be produced by friction, by chemical means or by irradiation, as it is well known for electric ions. I have observed also magnetophoresis[4], the counterpart to electrophoresis (Reuss, 1809), as well as coagulation of matter in homogeneous magnetic fields.

(2) I have also observed magnetophotophoresis; it is the movement of particles of the same kind and size in and against the direction of the lines of force in the homogeneous magnetic field[5] when irradiated by concentrated light. They reverse with the field, their velocity being a function of the field strength and light intensity. This phenomenon is the counterpart to electrophotophoresis[6].

(3) I have observed magnetolysis of water, which is proved by the appearance of oxygen (up to 12 per cent per volume) if the two ends of one piece of soft Swedish iron immersed in acidulated water (1–4 per cent acid by volume was used) are magnetized north and south. In the blank experiment without magnetic field, pure hydrogen (0·00 per cent oxygen) is evolved[7]. The quantity of gas evolved depends on the field strength. A so-called permanent magnet of Alnico alloy, fitted with pole-pieces of soft Swedish iron, gave the same result, namely, oxygen was found in the gases evolved and more of the latter was found to be coming from the north pole than from the south. The north pole was attacked more strongly than the south pole and in every experiment a larger volume of gas was collected from the north than from the south pole. Chemical analysis of gas was not made in every case. These phenomena prove again that magnetism is polar[8].

(4) The permanent magnets used lost a portion of their pole strength during the magnetolytic processes as determined by search coil and ballistic galvanometer, and were found to be at a steady state before and after the tests. This is the counterpart of the loss in pole-strength of Volta's pile during electrolysis. The loss of pole-strength per second gives the average intensity of the magnetic current flowing between the pole-faces in absolute magnetostatic units. Using the standardization of the International Electrotechnical Commission, Brussels-Scheveningen*, 1936, the intensity of the magnetic current in practical units can be defined as follows:

Pragilbert × Intensity of Magnetic Current = Watt.

The magnetic currents measured in these practical units have had intensities up to $1·7 \times 10^{-10}$.

(5) I have observed an electric vortex (whirl) around the iron wire connecting the two poles of an electromagnet or a so-called permanent magnet in a surrounding liquid bearing electrostatic charges. The same phenomenon occurs if the iron wire is covered by a thin electrically insulating material. This is the counterpart to the magnetic vortex (whirl) around the wire connecting the two poles of Volta's pile (using Oersted's own formulation). Using the dark field of the microscope, I have observed the circulation of a single electric charge, negative or positive, the direction of circulation being opposite in the two cases, this charge being on a bubble in liquid or on a solid particle in liquids or gases in or around the constant vertical homogeneous magnetic field. The intensity of the magnetic current measured electrically is equal to the work done by carrying a unit electric charge once about the entire magnetic current. This electric action of magnetic currents represents the third force in Nature besides the force of gravity and the well-known magnetic action of electric currents (Oersted, Biot-Savart, Lorentz). The use of this third force is *in principio* the magnetic motor[9].

(6) I have also observed that particles can carry simultaneously electric and magnetic charges; this has been concluded from the spiral tracks of bubbles and particles upwards and downwards in the constant vertical homogeneous magnetic field in gases and liquids. Their velocity of motion is of the order of magnitude of 10^{-2} cm./sec. in liquids and 1 cm./sec. in gases[10].

(7) It should be mentioned that there exists a polar movement in the geomagnetic field alone simultaneously with the north and south movements of microscopic particles of nickel or iron in gases at atmospheric pressure, when they are irradiated by light. They cease their movement when the magnetic field of the earth is compensated by an opposing field of the same strength and resume this movement if the compensating field is removed[11].

Furthermore, there is no ground for the doubt, raised by Mr. Kendall, about the validity of measurements of smaller charges than the electronic charge. I discovered and published this first in 1910 and finished this work in 1937, showing that on small

* For these data I am obliged to Brother Gabriel Kane, New York City.

spherical bodies of known density there are electrostatic charges smaller than the electronic charge. Using the same method, I found that the numerical value of the magnetic charge on a single particle, for example, of nickel in gas, can also be smaller than $4–5 \times 10^{-10}$ M.S.U.[12].

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Mechanisms for the Relaxation Theory of Viscosity

A RECENT communication by D. D. Eley and D. C. Pepper[1] describes experiments on the plastic flow of plasticized cellulose derivatives. They find that the flow velocity of compression of cylinders and extension of rods depends exponentially on stress at moderate stresses as the simple relaxation theory predicts[2,3], but at higher stresses flow velocity approaches linearity with stress. This behaviour at high stress leads them to question the applicability of the relaxation theory in general to flow problems.

We have observed this same phenomenon in the published data on other disperse systems, such as greases, paints and clay slips. In fact, the phenomenon appears to be characteristic of solid–liquid dispersions the flow of which has in the past been described by the Bingham yield-value equation.

The situation has been explained in the way which we now outline[4]. Consider a system where flow—or place exchange—involves the breaking of at least two types of bonds. Type 1 consists of strong bonds so that they flow according to a non-Newtonian law (at moderate stresses, the exponential law), while Type 2, being weak bonds, obeys the Newtonian law (that is, flow is proportional to stress). The total shear stress, f, is expressible as a sum

$$f = f_1 + f_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where f_1 is the shear stress acting on Type 1 bonds and f_2 on Type 2 bonds. Now the rate of shear of each type of bond is given by the hyperbolic-sine law according to the relaxation theory. For the Type 1 (strong) bonds this general law simplifies to the exponential law

$$\frac{ds_1}{dt} = \frac{\lambda}{\lambda_1} k_r e^{f_1 \lambda_2 \lambda_3 \lambda / 2kT}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

while for the Type 2 (weak) bonds the general law simplifies to the linear law

$$\frac{ds_2}{dt} = f_2/\eta_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Here $\lambda_2\lambda_3$ is the cross-section of the flowing unit on which the shear stress acts; λ_1 is the distance between neighbouring moving units in the direction normal to shear; λ is the distance jumped on each relaxation; k_r is the frequency of the relaxation jump in the direction of flow, at zero stress, and has a well-known form according to the statistical theory of reactions; η_2 is the viscosity due to the Type 2 bonds, which can also be expressed in terms of the dimensions of the unit of flow and the frequency of the relaxation jump for the Type 2 process[2]; k is the Boltzmann constant; T is the absolute temperature.

Now the condition that the two types of bonds shall yield at the same rate is that the shear-rates be equal:

$$\frac{ds_1}{dt} = \frac{ds_2}{dt} = \frac{ds}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The relation between total stress and shear-rate is thus

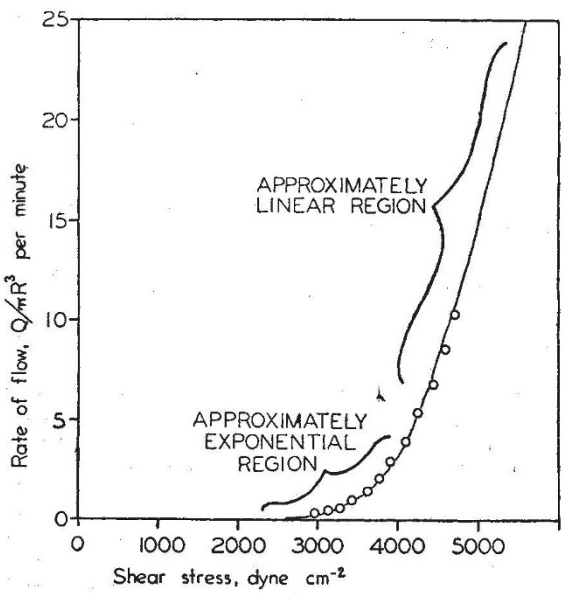
$$f = \eta_2 \frac{ds}{dt} + \frac{kT}{\lambda_2 \lambda_3 \lambda/2} \ln\left(\frac{\lambda_1}{\lambda k_r} \frac{ds}{dt}\right), \quad . \quad . \quad . \quad (5)$$

which in its simplest form is

$$f = \eta_2 \frac{ds}{dt} + a \log \frac{ds}{dt} + b \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In agreement with the results of Eley and Pepper, Eq. (6) gives a shear-rate which depends exponentially on stress at small stresses where the term for breaking of Type 1 bonds predominates, and a shear-rate which depends linearly on the stress at large stresses where the term for breaking of Type 2 bonds predominates. The application of Eq. (6) is illustrated in the accompanying graph, where the equation has been fitted to the data of Blott and Samuel on a lime-base grease[5]. It may be mentioned that the above treatment gives a theoretical explanation not heretofore offered for the curvature always observed at low stresses in 'yield-value' plots.

Two additional tests of the correctness of the present interpretation are available. The first is



THE CIRCLES ARE EXPERIMENTAL DATA FOR A LIME-BASE GREASE STUDIED BY BLOTT AND SAMUEL. THE CONTINUOUS CURVE IS A THEORETICAL CURVE CALCULATED FROM EQUATION 6.