is a very small number (of the order of about $10^{-12}T$); ρ_1 is of the order of τ and ρ_2 of the order of τ^2. As, moreover, $p = \frac{1}{3}(\rho - \rho_0)$, we have:

$$\rho = \bar{\rho} + \tfrac{3}{2}p + \tfrac{1}{8}\rho_2 = \bar{\rho}(1 + \tfrac{3}{2}\tau) + \tfrac{1}{8}\rho_2, \quad (5)$$

$$\rho_0 = \bar{\rho} - \tfrac{3}{2}p + \tfrac{1}{8}\rho_2 = \bar{\rho}(1 - \tfrac{3}{2}\tau) + \tfrac{1}{8}\rho_2. \quad (6)$$

In the second member of (5), the first term corresponds to the sum of the proper energies of the molecules (which is smaller than the proper energy of the element of matter they constitute), the second term to the classical kinetic energy of the relative translatory motion, and the third term to the relativistic correction. If the latter is neglected (which means neglect of v^4/c^4 in (3), (4)), we obtain from (5), (6):

$$\bar{\rho} \sim \tfrac{1}{2}(\rho + \rho_0). \quad (7)$$

Finally, it may be remarked that in the case where p is a function of $\bar{\rho}$ alone, so that the hydrodynamical integral $P = \int dp/\bar{\rho}$ exists, $mc^2(1 + P)$ is the average value per molecule of the so-called proper *enthalpy* or heat-content $E + pV$, so that[5]

$$T_{ij} = -\bar{\rho}(1 + P)i_i i_j + pg_{ij}. \quad (8)$$

D. VAN DANTZIG.

Technische Hoogeschool,
Delft.
March 22.

[1] van Dantzig, D., "On the Phaenomenological Thermodynamics of Moving Matter". To be published in *Physica*.

[2] Eddington, A. S., "The Mathematical Theory of Relativity", p. 122 (Cambridge, 1924).

[3] Synge, J. L., *Trans. Roy. Soc. Canada*, (3), III, **28**, 127–171 and 156 (1934). *Proc. Lond. Math. Soc.*, (2), **43**, 376–416 and 386 (1937).

[4] Jüttner, F., *Ann. Phys.*, (4), **34**, 856–882 (1911); (4), **35**, 145–161 (1911). *Z. Phys.*, **47**, 542–566 (1928). Tolman, R. C., *Phil. Mag.* **28**, 583–600 (1914).

[5] Cf. Pauli, W., *Enz. Math. Wiss.*, **2**, 692 (1920), where the older literature is mentioned.

Motion of the Spiral Nebulæ

THE shift of the spectrum lines of the spiral nebulæ towards the red is commonly accepted as evidence of a high velocity in the line of sight away from the solar system.

I venture to suggest that the shift may not be a Doppler effect at all; but the well-known genuine slowing down of atomic vibrations predicted by the Lorentz-Larmor electromagnetic theory, which has recently been conclusively demonstrated in laboratory experiments in the case of hydrogen canal rays by Ives and Stilwell[1].

On this interpretation, all the extra-galactic nebulæ must be regarded as rotating about the galaxy as centre, so that we have a velocity of revolution instead of a radially outward one; but its magnitude is even more staggering than the required radial velocity. If $\Delta\lambda$ is the increase in the wave-length, λ, the required radial velocity u is given by $\Delta\lambda/\lambda = u/c$, where c is the velocity of light; but the required transverse velocity v is given by $\Delta\lambda/\lambda = (1-v^2/c^2)^{-\frac{1}{2}} - 1$; or by $\Delta\lambda/\lambda = v^2/2c^2$ if v^4/c^4 is negligible. In this case the relation between v and u for the same shift is $v^2 = 2cu$.

Thus, taking the typical nebulæ velocities at distances of 10^7 and 10^8 light-years as 1,700 and 17,000 km./sec. respectively, the required transverse velocities work out as 32,000 and 100,000 km./sec. respectively. So nebulæ at these two distances would take 580 and 1,850 million years respectively to perform one revolution; this gives proper motions too small to have been detected so far.

Since the radial velocity u has been found to be proportional to the distance r, we shall have v^2/r as constant. Thus all the nebulæ possess approximately the same radial acceleration. If the nebulæ occupy a spherical volume, with rough symmetry, this means that the total mass inside a sphere of radius r is proportional to r^2. But the radial acceleration requires a much greater amount of mass than appears actually to be present. I find that the number of nebulæ, each of mass 3,500 million suns, which would be required inside spheres of 10^7 and 10^8 light-years, works out at 2×10^8 and 2×10^{10} respectively. This latter seems about 10,000 times too great. The acceleration might be accounted for by the supposition of cosmic dust between the nebulæ, of densities $2{\cdot}7 \times 10^{-25}$ and $2{\cdot}7 \times 10^{-26}$ gm./c.c. at 10^7 and 10^8 light-years, respectively, which shared in the general rotation of the system of nebulæ. This would give a mass of about 12 grams of material per sq. cm. of cross-section, lying between distances of 10^6 and 10^8 light-years, which, although it is only about 1 per cent of the earth's atmosphere, will be difficult to reconcile with no more absorption than actually exists, unless the material exists as separate atoms or molecules instead of as dust particles.

This possible rotation of the whole system of spiral nebulæ makes the estimated rotation of the galaxy require further investigation.

I put forward this suggestion on the motion of the spiral nebulæ to see if it can be found tenable in the face of criticism. I know it has its difficulties, especially as, so far as I know, no evidence of symmetrical distribution with respect to any axis has been discovered among the spiral nebulæ; but it avoids some of the difficulties associated with the idea of radial velocities.

ALBERT EAGLE.

The University,
Manchester, 13.
April 1.

[1] *J. Opt. Soc. Amer.*, **28**, 215–226 (1938).

Influence of Micelle Formation on Flotation

IT has been noted[1] that cetyl-trimethyl-ammonium bromide is a collector for (that is, induces floatability of) several different types of mineral. The minimum effective concentration of the compound (threshold concentration) required to induce flotation differs from mineral to mineral, but when the concentration has been increased to a value lying between 100 mgm. and 500 mgm. a litre, flotation ceases to be possible for all minerals. This is about the concentration (280 mgm. a litre) at which micelle formation of the ammonium salt becomes considerable[2].

We have recently found that flotation ceases to be possible in solutions of certain other paraffin chain compounds, for example, sodium cetyl sulphate and potassium laurate, at the concentration at which micelle formation occurs. Moreover, neutral salts, such as sodium and calcium chlorides, which diminish the concentrations necessary for micelle formation, also diminish the concentrations necessary to prevent flotation. It is concluded that there is a direct correlation between micelle formation and prevention of flotation.

Flotation is dependent upon orientated adsorption of the collector at the mineral surface, which enables contact with the air bubble to occur, but contact is hindered[1] when the air bubble is 'armoured' by adsorbed paraffin chain molecules and micelles. This