(and neutrons) are made of electrons and protons; in this case three independent parameters, of which one is the temperature, suffice to determine all the equilibrium properties of the assembly. If the nuclei are made, on the other hand, of protons and neutrons as the ultimate particles, very nearly the same treatment will suffice. In the simpler of these two cases, a parameter ξ is associated with the extranuclear electrons in the assembly and a parameter η with the extranuclear protons. Corresponding to any nucleus of mass number M_s and atomic number N_s there exists a parameter μ_s given by

$$\mu_s = \xi^{M_s - N_s} \eta^{M_s} \exp\left(-Q_s/kT\right)$$

where Q_s is the energy required to build the nucleus s out of electrons and protons. The number of nuclei present (in the equilibrium state) of sort s is then

$$\overline{X}_s = \mu_s(\partial/\partial\mu_s)\Sigma \log f[\mu_s \exp(\epsilon/kT)]$$

and there are other familiar expressions for the other equilibrium properties.

It may happen that these equilibria are established nearly perfectly in the stars. The writer hopes to publish the theory shortly.

T. E. Sterne*

Harvard University,
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* National Research Fellow.

Conductivity of Rare Gases Irradiated by Their Own Resonance Radiations

At the Atlantic City meeting of the American Physical Society the writers[1] reported on an investigation of the conductivity of rare gases irradiated with their own resonance radiations and on the effect of the addition of small traces of impurities on this conductivity. The conductivity was determined by the volt-ampere characteristics of a pair of parallel plane disk collectors in the irradiated gas. The currents obtained do not reach a saturation value at any of the pressures or voltages used (1–12 mm; 0–150 v). This observation was also indicated by Penning[2] and has been recently confirmed by Kenty.[3] The writers have attributed this lack of saturation to the collection of those ions formed in the outer volume of the gas as well as those formed in the region between the collectors. To test this hypothesis volt-ampere characteristics were taken for a pair of parallel plane disk collectors fitted with guard rings. The collectors which were 5 mm in radius and had guard rings 5 mm wide were separated 5 mm. Collectors and leads were insulated with glass except on the adjacent faces of the collectors and rings. When they were mounted at right angles to the tube axis so that the space between them was shielded from the direct radiation, then, except at the lowest pressures, no measurable current ($<10^{-10}$ ampere) flowed between the guarded collectors. The total current (to collectors and guard-rings), however, was the same as that previously observed between unguarded collectors. When the collectors were turned so that the primary radiation illuminated the space between them, appreciable currents were obtained and the much larger total current was of the same order of magnitude as before. In no case were the collector surfaces exposed to the primary beam.

These results lead to two conclusions: first, that the ions which give rise to the observed conductivity must be formed in the space between the collectors; and second, that any metastable atoms which may produce these ions must also be formed in this space. It is difficult to reconcile these results with the propagation of resonance radiation through the gas by diffusion. In previously reported experiments, where collectors were found to receive measurable currents when shielded from the direct primary radiation, the collectors were unguarded and the observed currents probably were due to the collection of ions formed in the space surrounding the collectors. These ions could reach the collector edges. Hence the difference between the currents received by such an unguarded collector when turned parallel and then perpendicular to the primary beam is not to be attributed solely to the effects of the direct and scattered radiations. In Ne which contains a trace of A, with the collectors floating with respect to the discharge, the currents measured to the guard rings may be ten to fifty times those measured to the inner disks. Moreover, the currents measured between the guarded collectors exhibit decided maxima for small collector voltages (<10 v). These were first observed by Penning[2] who attributed them to ions diffusing in from the surrounding volume when the field between the collectors was so small that the ions were not trapped by the guard rings. This explanation the writers believe to be correct. Penning's use of guarded cylindrical collectors did not involve a change in their orientation with respect to the primary radiation.

If resonance radiation is not propagated to any considerable extent by scattering or absorption and reradiation in cases such as these where impurities are present which dissipate the energy of the scattered radiation, one must look for a new explanation for the conductivity observed in a side tube at right angles to the main discharge tube. It is possible that some of the primary radiation may be reflected into the side tube by the tube walls. In this case the degree of reflection by the tube walls must be greater than has generally been supposed so that less of the primary radiation is absorbed by the walls than has been supposed. Kenty[3] has already suspected that this may be true. If the observed conductivity is due to the action of the direct primary beam rather than to that of

[1] Duffendack and Smith, Phys. Rev. **43**, 374 (1933).
[2] Penning, Zeits. f. Physik **78**, 7 and 8, 454 (1932).
[3] Kenty, Phys. Rev. **43**, 181 (1933).

the scattered secondary radiation it is difficult to explain the relatively large conductivity observed in rigorously purified gas under conditions such that the photoelectric action of the primary beam is very small. However, if the scattered radiation plays any important rôle one would expect at least measurable currents for any orientation of the collectors. More complete and accurate data are necessary before any final conclusions can be drawn. The experiments are being continued.

O. S. Duffendack
R. W. Smith

Department of Physics,
University of Michigan,
March 15, 1933.

The Torque on Faraday's Magnet

Much of the recent discussion[1] of the torque on Faraday's revolving magnet concerns merely the choice between several simple ways of making the calculation, all of which yield correct results. On the other hand there is also a natural desire to understand this torque as arising from the same simple laws that are definitely known to hold for forces upon currents alone and upon magnetized matter alone; and in regard to this point divergent views have developed owing to the fact that here the torques upon current and magnetized matter cannot be separated in experiment and the distinction between them must of necessity rest in part upon speculative hypothesis.

By considering simple examples it can be seen that in the present state of knowledge no general answer to the question can be given. Two different possible distributions of the current among the molecules of the magnet will be described which would be indistinguishable to an observing physicist and yet which are of such a nature that in one case the torque certainly acts upon the magnetized matter while in the other it just as certainly acts upon the current. These two examples thus confirm the conclusion reached by various authors[2] on the basis of electron theory that in such cases the distribution of the true forces as between current and magnetic matter must depend upon the exact path of the conducting electrons through the material.

For simplicity let us as usual give to the magnet the form of a cylindrical bar uniformly magnetized longitudinally and mounted so as to revolve freely about its axis, and let the current enter with symmetrical distribution about the middle of the bar and leave at a point on the axis at one end. We shall also suppose the external circuit to be so arranged that the current exerts no torque upon that part of itself which lies within the magnet. The total torque on the bar is then known to be $i\Phi/2\pi$ where i is the total current and Φ the flux of induction through the cross section at which the current enters.

First distribution of the current

Let the magnetized matter consist of very thin wedges meeting by their edges along the axis of the bar, and let the current flow entirely through similar wedge-shaped spaces left between these wedges of magnetic matter (Fig. 1a).

In this case the observed torque arises entirely from forces exerted upon the magnetic matter by the partial field H_i due to the current. In the spaces through which the current flows we have, besides H_i, only the relatively weak "demagnetizing" field H_m due to the magnet, which at most points in the bar has a direction opposite to that of the principal flux; the effect of this field, acting upon

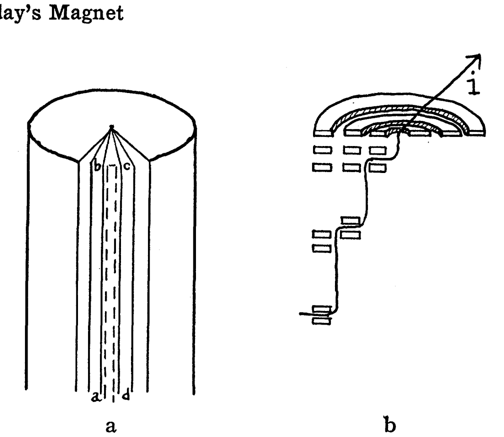

Fig. 1.

the current, is only to produce a small back-torque in opposition to the principal one.

At first sight one is tempted to think that, on the contrary, the field of the current cannot possibly cause the magnet to revolve because of the symmetry, for if the magnet turns through an angle $d\theta$ the work done upon one of the Amperian circuits in it is measured by the change in the flux through that circuit, and there seems to be no such change. The displacement $d\theta$ must, however, be taken indefinitely small; and just as the Amperian circuit begins its displacement it approaches the wedges of current on one side and recedes from those on the other (the current being of course assumed to stand still). The flux through the circuit will therefore vary a little, and as a matter of fact a calculation of this variation leads at once to the actual torque. Displacing a wedge through $d\theta$ is equivalent to transferring a slice of thickness $d\theta$ from one side to the other, say from ab to cd. If now we integrate along a path $abcdefa$, where e and f lie at the other end of the bar, $\int \mathbf{H}_i \cdot d\mathbf{s}=0$; but $\int_e^f=0$, and, since bc forms part of a circle enclosing the entire current, $\int_b^c \mathbf{H}_i \cdot ds=(d\theta/2\pi)4\pi i =2id\theta$. Thus $\int \mathbf{H}_i \cdot ds$ differs along the two sides of the wedge by $2id\theta$ and the work done upon the displaced slice, if its cross-sectional area is dA, will be $2iId\theta dA=id\theta d\Phi_m/2\pi$ (I = magnetization, $\Phi_m=4\pi AI$). The torque on the magnetized matter is thus $(i/2\pi)\int d\Phi_m$, and subtracting the

[1] Zeleny and Page, Phys. Rev. **40**, 299 (1932); **24**, 544 (1926); Kimball, Phys. Rev. **28**, 1302 (1926).

[2] Cf., e.g., Kennard and Wang, Phys. Rev. **27**, 460 (1926).