satisfy the relations div $\mathbf{U}=-(1/c)\partial\varphi/\partial t$; $V^2\mathbf{U}-(1/c^2)\partial^2\mathbf{U}/\partial t^2=0$; $V^2\varphi-(1/c^2)\partial^2\varphi/\partial t^2=0$, while important for endowing them with their usual significance in classical electromagnetic theory, play no part in the story of the invariance, even though they may play a part in the derivation of the ψ equation itself from certain assigned postulates. Hence, if in the ψ equation we replace $\mathbf{U}$ and φ by quantities obtained from them by operating with an invariant operator, the quantities so obtained, being still 4-vectors, will provide for the invariance of the new ψ equation. The operator kd/dt is an invariant operator when operating on a 4-vector, and P which is a function of kd/dt is an invariant operator. Hence, if in the ψ equation $\mathbf{U}$ and φ are replaced by $\mathbf{U}_1=P(\mathbf{U})$ and $\varphi_1=P(\varphi)$, the invariance will be preserved. The fact that the unmodified equation leads to (1) now results in the modified equation leading to (1) with $P(\mathbf{E})$ and $P(\mathbf{H})$ replacing $\mathbf{E}$ and $\mathbf{H}$. For a case where $\mathbf{H}$ is sensibly constant throughout the electron, it can then easily be shown that the modified right-hand side of (1) assumes the form $P(\mathbf{E})+[P(\mathbf{H})\mathbf{v}]/c$.

If we now take a system of axes in which the centroid is at rest, and if zero subscript refers to this system of axes, the equation assumes the form

$$(m/e)(d\dot{\mathbf{s}}_0/dt_0)=P_0(\mathbf{E}_0),$$

which after operation on both sides by P_0^{-1} yields

$$(m/e)P_0^{-1}(d\dot{\mathbf{s}}_0/dt_0)=\mathbf{E}_0.$$

On transforming back to the system of axes in respect to which the centroid moves with velocity $\mathbf{v}$, we obtain the desired equation with the radiation reaction terms, *viz.*,

$$\frac{m}{e}P^{-1}\frac{d}{dt}\frac{\mathbf{v}}{(1-v^2/c^2)^{\frac{1}{2}}}=\mathbf{E}+\frac{[\mathbf{vH}]}{c}.$$

The use of $\mathbf{v}$, the velocity of the centroid, in the operator P is admittedly artificial, although it provides a logically consistent story. However, it is possible to carry through the argument in a form in which $\mathbf{v}$ in this operator is replaced by the velocity $\mathbf{u}$ which occurs in $\rho\mathbf{u}$, the expression for the current density. The velocity $\mathbf{u}$ varies of course throughout space. A few restrictions have to be placed upon the argument in this form; but, it is believed that they are of a trivial nature.

The purpose of the whole investigation is not to establish the equation of motion with the radiation reaction terms, but to use the power to yield that equation as evidence in favor of the ψ equation which secures that end. It is admitted that such a method of deciding upon the ψ equation is not unique, but it is one which assumes a very natural relation to the mathematical structure of the theory. It is also realized that the spirit of the foregoing demonstration is that of the older forms of wave-mechanical theory rather than that of the more modern forms as typified by Dirac's theory. However, it is believed that the differences in the matter under discussion may be more apparent than real. If one admits the foregoing method of realizing the modified ψ equation, the ultimate result is simple in statement, and consists in replacing the perturbing field specified by $\mathbf{E}$ and $\mathbf{H}$ by a field specified by $P(\mathbf{E})$ and $P(\mathbf{H})$. Thus, for example, in the simplest case, for small velocities, $\mathbf{E}$ becomes replaced by $\mathbf{E}+\alpha\partial\mathbf{E}/\partial t$ as a first approximation.

W. F. G. SWANN

Bartol Research Foundation
of The Franklin Institute,
October 22, 1933.

Thermoelectric Force of Thin Films

We have recently had occasion to sputter very thin thermocouples of antimony and bismuth and have found a significant change of thermoelectric e.m.f. with varying thickness of bismuth. On the other hand, no change of e.m.f. with varying thickness of antimony has been observed.

Each metal was sputtered in purified argon on mica through suitable templates. Heavy layers of gold were sputtered over the ends of each metal to provide good electrical contact. The sputtering chamber was cleaned between each sputtering to assure freedom from contamination.

The e.m.f. of the thermocouples was measured within a day of manufacture with a Leeds and Northrup Type K potentiometer. The resistance of the couples was not sufficient to impair the sensitivity of the measurements. The couples were mounted in an apparatus composed of three sets of heavy copper blocks bored to permit circulation of water. The hot junction was in contact with the middle set, the two cold junctions with the outer sets. Temperatures were determined by thermometers immersed in the blocks. The reliability of the temperature measurements was tested with a copper-constantan couple.

All values given below for thermal e.m.f. are average values of several sets of measurements at different temperature differences between the hot and cold junctions.

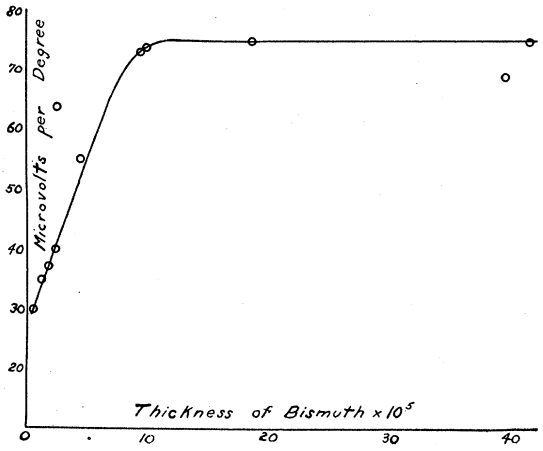

FIG. 1.

No variation of e.m.f. with thickness was found if the thickness of bismuth (2×10^{-4} cm) was held constant and the thickness of the antimony varied from 5×10^{-6} cm to 10^{-4} cm. When the thickness of antimony (3×10^{-5} cm) was held constant and the thickness of bismuth varied, a decided effect was found for thicknesses less than 10^{-4} cm. A plot of the results obtained are shown in Fig. 1.

Thicknesses above 10^{-4} cm yield a thermal e.m.f. corresponding to that of massive Bi-Sb. Burger and van Cittert,[1] in a study of evaporated films of Bi-Sb found the thermal e.m.f. of this couple the same as that of massive metal. However their thickness was 10^{-4} cm—corresponding to the flat part of our curve.

We have no theoretical reason to anticipate that the thermal e.m.f. of thin thermocouples should be different from that of the massive metals. It is possible, however, that the low e.m.f. is due to an effect of contamination by gases during the sputtering process—an effect which might manifest itself more in thin layers of metal. Nevertheless the smoothness of the curve seems to indicate a more regular change than such a contamination might produce. A different crystalline orientation in thin layers of bismuth seems more likely to be the cause. R. M. Holmes[2] found no effect of change of thermal e.m.f. with thin layers of gold and platinum. Whether the effect is present only for bismuth—a metal showing rather abnormal properties—or is a more general phenomenon will be the subject of further investigation.

E. A. JOHNSON[3]
LOUIS HARRIS[4]
Massachusetts Institute of Technology,
November 2, 1933.

[1] Burger and van Cittert, Zeits. f. Physik **66**, 210 (1930).
[2] R. M. Holmes, Phys. Rev. **22**, 137 (1923).
[3] Round Hill Research Division, Department of Electrical Engineering.
[4] Contribution from the Research Laboratory of Physical Chemistry, No. 314.

The Inert Gas Molecules

There is evidence from the behavior of the helium band spectrum in discharge tubes[1] carrying small currents that the helium molecule, although theoretically able to be produced in any excited state, is actually produced under discharge conditions from one normal and one metastable helium atom. The reaction can be represented by

$$He(1^{1,3}S)+He(2^{1,3}S)\rightarrow He_2(2^{1,3}\Sigma).$$

Since the visible helium bands require further excitation of the He_2 molecule for production of their initial states, it follows that the molecule formed in the first instance must have a sufficiently long lifetime for it to encounter an electron able to excite it further, before it passes alternatively to the unstable $1^1\Sigma$ ground state. From electrical analysis of the discharge[2] it can be shown that this requires the molecule first formed to be metastable, which is true of the $2^3\Sigma$ state, but not of the $2^1\Sigma$ state. It appears then that the possibility of observing the visible helium band spectrum at all is closely associated with the metastability of the $2^3\Sigma$ level.

This also gives a reason for expecting that the band spectra of the molecules Ne_2, A_2, etc., will be difficult, if not impossible to excite, for, compared with He_2, any metastability will be less strong on account of the greater number of electrons to the molecule. This will not however impair the efficiency of "quenching" of metastable atoms of these gases by their own normal atoms, a reaction of the type of the above equation being followed by emission of ultraviolet radiation in a transition to the spontaneously dissociating molecular ground state. The chance that a molecule will be formed, temporarily or otherwise, remains nevertheless smaller and is probably $<10^{-6}$ per kinetic theory collision between the parent atoms in the discharge.[1]

K. G. EMELEUS
O. S. DUFFENDACK
University of Michigan,
November 6, 1933.

[1] Emeleus and Duffendack, Phys. Rev. **44**, 322A (1933).
[2] Details of the calculations will be published later.

Disintegration of Fluorine Nuclei by Neutrons and the Probable Formation of a New Isotope of Nitrogen (N^{16})

Three thousand two hundred pairs of photographs of a large Wilson cloud chamber filled with a mixture of 30 percent by volume of difluor-dichlor-methane with 70 percent of helium exhibit ten nuclear disintegrations. The momentum and energy relations, together with other evidence, indicate that most, and probably all of these are disintegrations of fluorine nuclei.

Each nucleus which disintegrates is found to break apart into two parts, one of which has from two to eleven times the range of the other. The line density of the two fog tracks, which are coincident with respect to time of formation, is found to be approximately the same for the light as for the heavy nucleus. The only known nucleus which gives the relations found for the lighter particle is that of helium. Thus for disintegrations in which the neutron is captured the reaction may be considered to be represented by

$$F_1^{19}+n_1^1\rightarrow F_2^{20}\rightarrow N_2^{16}+He_0^4,$$

in which the subscripts represent the isotopic numbers and the superscripts the atomic masses.