

ably not adequate to describe the motion of a charged meson in orbits of radius comparable to  $r_0 = e^2/\mu c^2$ , because the reaction of the meson to its own field becomes important at such distances. Apart from this possibility, however, there is a formal method of saving the solutions for the meson wave. Suppose the elementary nucleon to have a mass,  $M$ , and a magnetic moment in the direction of its spin of  $\nu$  characteristic magnetons,  $(\nu e\hbar/2Mc)$ . If we put the vector potential due to this moment in the Proca equations, we may analyze the solutions by methods and approximations previously used on Dirac's equations.<sup>5</sup> This has been done for the  $S+D$  meson wave alluded to above, with the result that Eq. (1) is replaced by one for the lower eigenvalue:

$$d^2/dr^2 \rightarrow \frac{1}{2}(\nu e^2/Mc^2)^2/r^4 \text{ as } r \rightarrow 0 \quad (2)$$

for all states of finite energy. Thus the mesons face a repulsive potential at very small values of  $r$ , and a complete set of acceptable solutions should exist.

Depending upon the value of  $\nu$  and  $M$  and the more exact evaluation of the radiation reaction on the meson, the magnetic forces may be of importance in determining the nature of the bound meson-nucleon states. In particular, such forces often lead to  $r^{-3}$  attractive potentials at intermediate radii and, in the case of Dirac's equations in the field of an uncharged magnetic dipole, one bound state has been found due to them, under the approximations made (reference 5). It appears possible, therefore, to make an explicit model for bound meson-nucleons systems that would lead to the type of nuclear forces proposed by Landau and Tamm,<sup>3</sup> i.e., those of purely electromagnetic type, without first evaluating the radiation reaction. Owing to attractive magnetic forces, the elementary nucleon may possibly bind more than one meson, so that the proton could be a composite system as well as the neutron.

<sup>1</sup> I. Tamm, Phys. Rev. **58**, 952 (1940).

<sup>2</sup> H. C. Corben and J. Schwinger, Phys. Rev. **58**, 953 (1940).

<sup>3</sup> L. Landau and I. Tamm, Phys. Rev. **58**, 1006(L) (1940).

<sup>4</sup> L. Landau, Phys. Rev. **58**, 1006(L) (1940).

<sup>5</sup> C. L. Critchfield, Phys. Rev. **71**, 258 (1947).

### Erratum: Transition from Classical to Quantum Statistics in Germanium Semiconductors at Low Temperature

[Phys. Rev. **71**, 374 (1947)]

VIVIAN JOHNSON AND K. LARK-HOROVITZ  
Purdue University, Lafayette, Indiana

THE following corrections should be made in our Letter to the Editor of the above title:

(1) The sentence at the end of the first paragraph should read ". . . between impurity centers, while the constant  $D$  is to be determined from the experiments."

(2) The last equation should read

$$\rho_l = 6270n^{-1} \text{ ohm-cm.}$$

(3) The sentence reading "Thus the transition from classical to quantum statistics leads to a constant residual resistance due to impurity scattering in degenerate samples, in agreement with experiment," which appears below Table I, should have been the last sentence of the text.

### Electrostatic Field Strengths in Molecules and Nuclear Quadrupole Moments

C. H. TOWNES

Bell Telephone Laboratories, Murray Hill, New Jersey

May 21, 1947

THE magnitude of coupling between nuclear quadrupole moments and electric fields in certain molecules, as determined from microwave spectroscopy, has been given.<sup>1-3</sup> Since the quadrupole coupling involves the product of the nuclear quadrupole moment and the second derivative of the electric potential at the nucleus, excluding the effect of charge in a small sphere around the nucleus,  $[eQ(\partial^2 V/\partial z^2)]$ , a knowledge of  $\partial^2 V/\partial z^2$  is necessary in order to determine the quadrupole moment,  $Q$ . Nordsieck<sup>4</sup> has calculated this quantity for the hydrogen molecule, but a similar calculation for other molecules appears very tedious. It is here proposed that  $\partial^2 V/\partial z^2$  may be determined in many cases from atomic data. In determining this quantity, the distortion of the spherical atomic electron distribution around each nucleus due to its proximity to other nuclei must be considered for molecules such as  $H_2$  and the alkali halides. However, in case a heavy nucleus is covalently bonded in a molecule by use of one or two  $p$  electrons, the effect of the resulting non-spherical distribution of charge inside of the valence shell is very large, and contributions to  $\partial^2 V/\partial z^2$ , because of distortion of the atomic electron distribution, are negligible by comparison. In such cases  $\partial^2 V/\partial z^2$  is large and is easily calculable by the same method as is used for determination of quadrupole moments from atomic spectra.<sup>5</sup> If, on the other hand, the atomic state which is approximated by an atom in a molecule has a spherical distribution of electrons, then  $\partial^2 V/\partial z^2$  is small and much more difficult to calculate.

Assuming, then, a heavy nucleus bonded in a molecule with a simple covalent  $p$  bond, the value of  $\partial^2 V/\partial z^2$  is fairly accurately given by  $(8e\Delta\nu/15Z_1R\alpha^2a_0^3)$  e.s.u., where standard spectroscopic notation is used, and  $\Delta\nu$  is the fine structure separation for an isolated atom in the same state. Actual values of  $\partial^2 V/\partial z^2$ , of quadrupole couplings,<sup>1</sup> and of quadrupole moments for Cl and Br nuclei, are collected in Table I. The sign of  $\partial^2 V/\partial z^2$  corresponds to an excess posi-

TABLE I. Quadrupole coupling and moment for Br and Cl nuclei.

Molecule	Nucleus	$\partial^2 V/\partial z^2$ (e.s.u.)	Quadrupole coupling [ $eQ(\partial^2 V/\partial z^2)$ in mc]	Quadrupole moment ( $Q$ in $\text{cm}^2$ )
BrCN	Br <sup>79</sup>	$48 \times 10^{18}$	720	$0.21 \times 10^{-24}$
	Br <sup>81</sup>	$48 \times 10^{18}$	556	$0.16 \times 10^{-24}$
ClCN	Cl <sup>35</sup>	$17 \times 10^{18}$	84	$-0.067 \times 10^{-24}$
	Cl <sup>37</sup>	$17 \times 10^{18}$	64	$-0.051 \times 10^{-24}$

tive charge located on the molecular axis. The Br quadrupole moments obtained here are consistent with a rough estimate which can be made from atomic spectra.<sup>6</sup> In further justification of the procedure used, it should be observed that effects caused by distortion of the atomic wave functions and proximity of other nuclei will be of the order of magnitude of the contribution of one electron