at about 56 degrees caused Millikan to assume that the incoming radiation must consist of electrons.

However, proton energies cannot be directly read off an electron energy scale. This may be verified by using the formula employed by Lemaitre and Vallarta[4] to calculate, in stormers, the particle energy, x, necessary to penetrate the field of a magnetic dipole of moment M to a distance, r, equal to the radius of the earth (6370 km).

$$x=r(mv/eM)^{\frac{1}{2}},$$

where e, v, and m are, respectively, the charge, velocity, and relativistic mass of the particle.

Assuming that any atom of mass M_A emits a pair of oppositely directed particles each of mass m', with an energy due to the complete annihilation of the remainder of the atom, then

$$\tfrac{1}{2}(M_A-2m')c^2=m'c^2[(1-\beta^2)^{-\frac{1}{2}}-1].$$

From this, it may readily be seen that the relativistic mass $m'/(1-\beta^2)^{\frac{1}{2}}=\frac{1}{2}M_A$. Thus the relativistic mass, m, is constant for any particle emitted by a given atom-annihilation process. In particular, electrons or protons emitted in a helium-annihilation process have a relativistic mass of 3.32×10^{-24} g.

Accepting the values of $M=8.04\times10^{25}$ e.m.u. and $e=1.6\times10^{-20}$ e.m.u., then $x=0.177\sqrt{\beta}$, where β has been written for v/c, and may be calculated from the relativistic and rest mass values. For an electron of 1.87×10^{9} ev, $\beta=0.999$, whence $x=0.177$ stormers. For a proton of 0.93×10^{9} ev, $\beta=0.864$, whence $x=0.165$ stormers, which corresponds to an electron energy of 1.61×10^{9} ev.

On referring to the Lemaitre-Vallarta curves, it is seen that the difference in these particle energies, for vertical incidence, corresponds to a latitude difference of about $1\frac{1}{2}$ degrees, which is within the uncertainty limits of existing data on the latitude of the helium incoming radiation. Thus there is no experimental evidence to suggest that protons could not form the majority of the incoming radiation, thereby removing the principal objection to Millikan's atom-annihilation hypothesis.

[1] R. A. Millikan, Neher, and Pickering, Phys. Rev. **63**, 234 (1943).
[2] Millikan, Neher, and Pickering, Phys. Rev. **61**, 397 (1942).
[3] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 503 (1936).
[4] G. Lemaitre and M. S. Vallarta, Phys. Rev. **43**, 809 (1933).

Primary Cosmic-Ray Protons and the Atom-Annihilation Hypothesis

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August 8, 1947

IN a paper which appeared in the Physical Review [**61**, 397 (1942)] we stated in discussing the atom-annihilation hypothesis (see reference 4, page 398): "It would make no difference so far as all the results considered in this paper are concerned whether the charged particles are electrons, mesotrons, or protons, for at the very large energies here involved the effect of a magnetic field is essentially the same upon them all."

But in a paper in the Physical Review [**63**, 234 (1943)] we incorrectly stated (see page 245): "If, then, the transformation of rest mass energy in the case of the helium atom gave rise to a pair of protons rather than a pair of electrons, then the latitude of first entrance of these helium annihilation rays would be considerably north of Saskatoon instead of at mag. lat. 54 N computed from the Lemaitre-Vallarta curves as the first latitude of entrance of helium annihilation rays on the assumption that the whole rest mass of the helium is transferred into an *electron* pair."

In a subsequent article found in the same journal [Phys. Rev. **66**, 295, reference 1 (1944)] this last statement was corrected, as follows: "The only choice is between an electron pair and a proton pair, but the difference between the latitude of entrance of electrons and protons entering the earth's magnetic field from this mode of origin is in no case, not even in the case of He annihilation rays, large enough to be detected with the resolving power of the experimental techniques we have so far used."

In other words, we here corrected the contradiction between the two statements made in the 1942 and 1943 articles, reaffirming the validity of the 1942 statement and admitting our slip in the 1943 statement after recomputing the latitude of entrance of protons and finding it, within the limits of our observational uncertainty, the same as the latitude of entrance of electrons.

Further, Dr. Dana T. Warren in an article in Phys. Rev. **66**, 252 (1944) also called attention to the contradictory character of our two statements and made essentially the same computations which Mr. Turner has herein made and reached a conclusion identical with his. Therefore it is probably desirable now to emphasize the fact that there is no disagreement by anybody on the point here involved.

Microwave Spectra of Linear Molecules

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July 24, 1947

WORK on the spectra of certain linear molecules near 1.25-cm wave-length has continued in these laboratories. Some results not previously reported are described below.

The $O^{16}C^{12}S^{33}$ transition $J=1\rightarrow2$ has been found at 24020.3 ± 0.1 Mc. The interval between this line and the $O^{16}C^{12}S^{32}$ line is 305.75 ± 0.05 Mc. Combining this result with the value 594.59 ± 0.04 obtained by others[1,2] for the interval between the $O^{16}C^{12}S^{32}$ and $O^{16}C^{12}S^{34}$ lines, one can compute the ratio of the mass differences $(S^{33}-S^{32})/(S^{34}-S^{32})$ to be 0.49985 ± 0.0001. The result is only in fair agreement with the value 0.50038 ± 0.0002 obtained from Mattauch.[3] This calculation assumes the quadrupole couplings for S^{33} and S^{34} (to be discussed below) are zero.

It should be pointed out that the inter-nuclear distances for the OCS molecule given by other workers[1,2] have not included the effects of zero-point vibrations, and that the actual errors for the inter-nuclear distance determinations

can be considerably greater than the quoted errors of about 0.005A. Because of the zero-point vibrations, the average bond distances in isotopic molecules may not be the same, and this shift in bond length due to difference in isotopic mass must be known and accounted for before microwave data on moments of inertia can give very accurate values for inter-nuclear distances. The effect of the zero bending-mode vibration on average moment of inertia has been obtained in this laboratory by measurement of the rotation transition $J=1\rightarrow 2$ for OCS molecules excited to the first bending mode ($v_2=1$). In standard notation, this effect may be expressed in terms of a parameter α_2, which has been found to be 10.6 Mc, and its presence produces a correction of about 0.03A in the inter-nuclear distances. Corrections for the other modes of vibration are of the opposite sign, and hence may largely compensate the effect of the bending mode, but until these corrections are known they result in considerable uncertainty in determination of inter-nuclear distance from microwave data. On the other hand, for the intervals between the lines of OCS^{32}, OCS^{33}, and OCS^{34}, the corrections are to a good approximation proportional to the change in mass of the sulphur atom, so that with accurate measurements of the intervals, the ratio of mass differences $(S^{33}-S^{32})/(S^{34}-S^{32})$ may be obtained to an accuracy of about one part in ten thousand without an exact knowledge of the corrections for zero-point vibrations.

Quadrupole splittings of the OCS^{34} and OCS^{33} lines were looked for, but no splitting was found. This means that the S^{34} quadrupole coupling cannot be greater than 1 Mc, or estimating the derivative of the electric field at the nucleus, $\partial^2 V/\partial z^2$, by the method previously described,[4] the S^{34} quadrupole moment must be less than 0.001×10^{-24}. Since this is extremely small (sixty times smaller than the moments of the nuclei of similar size Cl^{35} and Cl^{37}) it seems likely that the spin of S^{34} is zero which necessitates a quadrupole moment equal exactly to zero. Although the OCS^{33} line is very weak because of the low abundance (0.78 percent) of S^{33}, it was probably observed sufficiently well to rule out the possibility of a quadrupole coupling greater than 5 Mc for S^{33}. By reasoning similar to that applied to S^{34}, it seems likely that the S^{33} spin is $\frac{1}{2}$, making the quadrupole moment zero of necessity.

Quadrupole effects due to C^{13} were also looked for in the $O^{16}C^{13}S^{32}$ line found at $24{,}248.1\pm 0.3$ Mc, and in the $Cl^{35}C^{13}N^{14}$ transition $J=1\rightarrow 2$. No quadrupole effect was found; the quadrupole coupling in these cases must be less than 0.5 Mc. This is, as in the case of the sulphurs, a good indication that the C^{13} spin is $\frac{1}{2}$, and agrees with the C^{13} spin determination from band spectra announced by Jenkins[5] shortly after these measurements were made.

A set of eleven lines due to $Cl^{35}C^{12}N^{14}$ molecules in the excited bending mode of vibration were found. They are fitted nicely by assuming the same spin and quadrupole coupling for Cl^{35} as previously given. The energy levels follow the formula for symmetric top molecules with $K=1$, since an angular momentum along the molecular axis is present in these excited molecules.

The excited state ClCN lines of course show l-type doubling as did those for BrCN. Table I lists frequency difference between the two sets of lines produced by l-type doubling in the 1.25-cm region for these molecules and for OCS. It may be noted that the experimental splitting is consistently larger by 40 percent than the theoretical values. Dr. J. Bardeen has pointed out to us that the theory of Nielsen and Shaffer[6] needs to be corrected by dividing by a factor of two, and the theoretical values are given after making this correction.

TABLE I. l-type doubling values.

Molecule	Measurement	Theory
OCS	25.6 Mc	18.7 Mc
ClCN	34.8 Mc	24.0 Mc
BrCN	24.6 Mc	18.2 Mc

[1] T. W. Dakin, W. E. Good, and D. K. Coles, Phys. Rev. **71**, 640 (1947).
[2] R. E. Hillger, Washington meeting Am. Phys. Soc., paper B6 (1947). These authors pointed out the zero-vibration errors in oral presentation of their paper.
[3] J. Mattauch, *Nuclear Physics Tables* (Interscience Publishers, Inc., New York, 1946), p. 128.
[4] C. H. Townes, Phys. Rev. **71**, 909 (1947).
[5] F. A. Jenkins, Washington meeting Am. Phys. Soc., paper L12 (1947).
[6] H. H. Nielsen and W. H. Shaffer, J. Chem. Phys. **11**, 140 (1943).

Calculation of the Shear Elastic Constants of the Alkali Halides

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July 31, 1947

THE shear elastic constants for copper and certain of the alkali metals have been calculated by Fuchs[1] from theoretical considerations. We report here the results of a similar calculation of these constants for several alkali halides. The shear elastic constants are determined primarily by changes in the Coulomb energy and in the non-Coulomb ion-ion exchange interaction energy.

The two shear elastic constants for cubic crystals are $C_{11}-C_{12}$ and C_{44}. For a NaCl type of lattice the electrostatic contributions to these constants arise (1) from the interaction of each ion with the face-centered cubic lattice of ions of the same sign and (2) from the interaction of each ion with the lattice of ions of opposite sign. These contributions have been evaluated in Table I in units of e^2/δ per molecule, where e is the electronic charge and δ is the lattice constant. Column 1 shows the contribution from the ions of like sign as calculated by Fuchs,[1] column 2 shows the contribution of the unlike ions which we have calculated, and column 3 shows the total electrostatic contribution. The calculations are based on the Ewald method[2] of treating electrostatic energy of the lattice.

For the ion-ion interaction the nearest neighbors and the next nearest neighbors have been considered, using a

TABLE I. Electrostatic contribution to the shear elastic constants of the alkali halides in units of e^2/δ per molecule.

	Like ions[1]	Unlike ions	Sum
$C_{11}-C_{12}$	0.2115	−5.525	−5.31
C_{44}	0.9479	1.60	2.55