hypothesis. Moreover, the activation energy in range *II*, after correcting for the slope in range *I*, is substantially equal to the work function, thus confirming his picture. If Vink's conclusions are accepted, then the previous assumption of a donor level about 1.4 ev below the conduction band appears unwarranted. In fact, Vink's slope in range *I* would lead one to expect a smaller value of $\Delta\epsilon$, which might be as low as 0.1–0.4 ev in an active cathode.

What we want especially to point out here is that donors this close to the conduction band are highly, if not completely, ionized above 800°K for $n_b=3\times10^{17}/\text{cm}^3$. If one assumes completely ionized donors and a negligible contribution from the full band,[8] then the emission equation becomes[3]

$$i=n_be(2\pi m)^{-\frac{1}{2}}(kT)^{\frac{1}{2}}(1-r)\exp(-\chi/kT). \tag{3}$$

Note that the work function in this case is equal to χ and should be determined from an $i/T^{\frac{1}{2}}$ plot; using Wright's data,[5] we obtain $\chi=1.08$ ev. If n_b is again taken as $3\times10^{17}/\text{cm}^3$ and $r=0$, Eq. (3) predicts an emission density at 740°C of 1.0 amp/cm², compared to the experimental d.c. values of the order of 0.5 amp/cm². For the case of strongly, but not completely, ionized donors, the calculated value is somewhat lower than 1.0 amp/cm². Hence, the concept of highly ionized donors greatly improves the agreement with experiment for well-activated (Ba–Sr)O cathodes.

We are indebted to Professor G. E. Uhlenbeck for the final form of this letter and to Dr. O. S. Duffendack for his encouragement and support.

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[7] Vink also reports a third region of still different shope above 1000°K which does not concern us here.
[8] With a thermal band separation as small as 2 ev, the full band contribution at 1200°K is negligible.

The Detection of Heavy Particles in the Primary Cosmic Radiation*

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July 14, 1949

UTILIZING a new technique which has rendered feasible the selective detection of the charged components of cosmic radiation, the composition of the primaries has been established and heavy particles have been discovered. The results, originally described only in Navy reports[1] have subsequently been confirmed by investigations involving photographic plates and cloud chambers.[2] Although it had heretofore been our intention to withhold publication pending the completion of an elaborate series of experiments of the type to be described, preoccupation with other matters has repeatedly introduced delays to such an extent that it now seems expedient to report briefly upon the results obtained thus far.

The method utilizes G-M counters filled under conditions exploiting the dependence of the probability of discharge upon specific ionization. The combination of such counters into a coincidence train, and the establishment of a minimum range through interposed absorber, result in a device capable of discriminating violently among different types of particles.

It is well known that the probability of discharge E (the so-called "efficiency") of a G-M counter is determined by the probability that a particle will produce at least one ion pair during its traversal of the sensitive volume of the counter.

TABLE I. Dependence of counting efficiency E upon specific ionization. $E=1-e^{-\bar{l}sp}$; coincidence counting efficiencies ${}_sE^n$, and discrimination obtainable for particles of various specific ionizations.

${}_1E^1$	n	${}_1E^n$	${}_sE^n$	${}_sE^n/{}_1E^n$
25%	4	0.4%	24%	60
18%	4	0.1%	9%	90
50%	8	0.3%	61%	203
37%	8	0.04%	25%	625

TABLE II. Typical flight, 4 counters (6 cm Hg of H_2) in coincidence.*

Particle	Relative prim. ion.	E^4
Electron	1	0.02
Mesotron	1	0.02
Proton	1	0.02
Helium	4	0.50
Lithium (and heavier)	≥10	≥0.96

* E^4 = expected counting efficiency for various particles penetrating terrestrial magnetic field. Observed counting efficiency above 90,000 ft. $E_0^4=0.23\pm0.03$.

E is given by the expression:[3]

$$E=1-e^{-\bar{l}sp}, \tag{1}$$

where s = number of ion pairs per cm produced at standard pressure in the gas with which counter is filled, $\bar{l}$ = average path length through the counter, p = pressure in counter (fraction of an atmosphere). In the case of a coincidence train, the probability of registering an event is determined by the product of the probabilities of discharge of the individual components. Hence, for identical counters, this is given by:

$$E_n=E^n, \tag{2}$$

where E_n is the probability of an n-fold coincidence.

Table I indicates the degree of discrimination which it is possible to realize by means of a suitable combination of G-M counters filled at very low pressure. The notation employed in this table is self-explanatory. It is seen that heavily-ionizing particles may be detected under conditions precluding the triggering of an event by particles of minimum ionization. Table II summarizes the pertinent quantities characterizing a particular typical experiment. The final column labeled E^4 indicates the expected counting efficiency for various particles having sufficient energy to penetrate the terrestrial magnetic field. The experimentally-observed counting efficiency near the "top of the atmosphere" equal to 0.23 ± 0.03 should be compared with that of 0.02 expected for a primary radiation consisting entirely of protons.

The method of analyzing the primary cosmic radiation on the basis of these experiments is exemplified by the following set of equations:

$$1=f_P+f_\alpha+f_H, \tag{3}$$
$$E^4=f_PE_P^4+f_\alpha E_\alpha^4+f_HE_H^4, \tag{4}$$
$$\bar{E}^4=f_P\bar{E}_P^4+f_\alpha\bar{E}_\alpha^4+f_H\bar{E}_H^4. \tag{5}$$

Here f_A represents the fraction of the total primary radiation comprised of particles of type A; E_A^n is the efficiency of an n-fold coincidence train for particles of type A; E^n is the observed net counting efficiency; P, α, and H identify protons, helium nuclei, and heavier particles respectively. All quantities E are determined experimentally, and from a comparison among the data obtained in independent experiments where new values of E appear, the fractions f_A may be computed. It is seen that $(k-1)$ flights determine the relative intensities of k types of particles.

Flights embodying counters filled at different pressures, and containing different quantities of interposed absorber, are still in progress. Heavy particles were first detected during a free-balloon ascent on July 11, 1947, in which events ascribable to primaries of $Z \geq 2$ were observed at altitudes exceeding 15 mm of Hg. It has since become possible, through analyses such as that described above, to ascertain that approximately one-third of the incoming cosmic rays are alpha-particles (the presence of helium atoms was originally predicted by Swann[4]), and the remainder predominantly protons, with a small percentage of particles having higher atomic numbers.

The possible influence of stars, bursts, air showers, etc., upon these experiments has been investigated by means of an arrangement whereby an out-of-line counter replaces an in-line counter in the quadruple coincidence train at predetermined altitudes during the course of a flight. The relative frequency of out-of-line events compared with that of events produced by single particles makes it improbable that spurious effects are responsible for the high efficiencies observed.

* Assisted by the Joint Program of the ONR and the AEC.

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Nuclear Quadrupole Moments and Shell Structure

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August 10, 1949

It is generally accepted that positive quadrupole moments (Q) indicate nuclei which are elongated in the direction of the spin (I) axis, and *vice versa* for negative Q. In this note it is suggested that the spatial distortion of nuclei, and hence Q values, arise in the first order of approximation from incomplete proton and/or neutron sub-shells.

In Table I are tabulated the nuclei for which Q values are known.[1,2] On the basis of nuclear shell theory, level assignments of the nucleons in the incomplete shells are given in column 4 of this table. These assignments lead to conclusions as to the signs of the quadrupole moments, which are also given in column 4. In drawing these conclusions the following assumptions were made: (1) The shapes of nuclei are determined by the probability-density distributions $\psi\psi^*$ of the independent nucleons in the incomplete shells. (2) Completely closed shells or sub-shells (which are spherically symmetrical) do not contribute to Q. Likewise, since pairs of nucleons make no contribution to I, unfilled sub-shells with even numbers of nucleons to a first order of approximation make no contribution to Q. Accordingly, only incomplete shells with odd numbers of nucleons are listed in the table. (3) In an unfilled shell having an odd number of nucleons, the "unpaired" nucleon has an m_j value equal to I, and the other nucleons distribute themselves in pairs among the remaining values of m_j (m_j is the magnetic quantum number with respect to the I field). (4) A sub-shell with only one nucleon in the state $m_j = |I|$ endows the nucleus with a negative Q value. A sub-shell with an odd number of nucleons in states $m_j = |I|, \pm\frac{1}{2}, \pm\frac{3}{2}, \cdots$ generally will produce a nucleus of positive Q value, the magnitude being the greater the more the nucleons are concentrated in the states of lower values of m_j.

The order of the sub-shells follows closely that given by Mayer.[3] There is a certain amount of arbitrariness in selecting sub-shells for the higher Z and N nuclei, but for Z or $N \leqslant 20$ the latitude of selection is fairly narrow. The case of ${}_{19}K^{39}$ is of interest because the shell interpretation indicates a positive Q value and the tabulated negative value is as yet only an estimate.[2] Other particularly rigid selections are In^{113}, In^{115}, Sb^{121}, Hg^{201} and Bi^{209}, which occur in the regions of closed shells. The experimental values in these cases, and in all other cases with the possible exception of

TABLE I. Interpretation of quadrupole moments.

Nucleus	Q	I	Nucleon configuration of unfilled shells*
${}_{1}H^{2}$	+0.0027	1	$1s_{1/2}$ proton, $1s_{1/2}$ neutron. Q = zero
${}_{3}Li^{6}$	~0	1	$1p_{1/2}$ proton, $1p_{1/2}$ neutron. Q = zero
${}_{3}Li^{7}$	−0.020	3/2	$1p_{3/2}$ proton, $m_j = \|3/2\|$ negative Q
${}_{5}B^{10}$	+0.060	3	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$; $3p_{3/2}$ neutrons, $m_j = \pm 1/2, \|3/2\|$ } positive Q
${}_{5}B^{11}$	+0.030	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{7}N^{14}$	+0.020	1	$1p_{1/2}$ proton, $1p_{1/2}$ neutron. Q = zero
${}_{13}Al^{27}$	+0.156	5/2	$5d_{5/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \|5/2\|$ positive Q
${}_{16}S^{33}$	−0.050	3/2	$1d_{3/2}$ neutron, $m_j = \|3/2\|$ negative Q
${}_{17}Cl^{35}$	−0.079	3/2	$1d_{3/2}$ proton, $m_j = \|3/2\|$ negative Q
${}_{17}Cl^{37}$	−0.062	3/2	$1d_{3/2}$ proton, $m_j = \|3/2\|$ negative Q
${}_{19}K^{39}$	−0.030	3/2	$3d_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{19}K^{41}$	−0.020	3/2	$3d_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{29}Cu^{63}$	−0.010	3/2	$1p_{3/2}$ proton, $m_j = \|3/2\|$ negative Q
${}_{29}Cu^{65}$	−0.010	3/2	$1p_{3/2}$ proton, $m_j = \|3/2\|$ negative Q
${}_{31}Ga^{69}$	+0.232	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{31}Ga^{71}$	+0.147	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{33}As^{75}$	+0.300	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{35}Br^{79}$	+0.280	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{35}Br^{81}$	+0.230	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{36}Kr^{83}$	+0.150	9/2	$7g_{9/2}$ neutrons, $m_j = \pm 3/2, \pm 5/2, \pm 7/2, \|9/2\|$ positive Q
${}_{37}Rb^{87}$	+0.170	3/2	$3p_{3/2}$ protons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{49}In^{113}$	+1.300	9/2	$9g_{9/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \pm 5/2, \pm 7/2, \|9/2\|$ positive Q
${}_{49}In^{115}$	+1.17	9/2	$9g_{9/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \pm 5/2, \pm 7/2, \|9/2\|$ positive Q
${}_{51}Sb^{121}$	−0.90	5/2	$1d_{5/2}$ proton, $m_j = \|5/2\|$ negative Q
${}_{53}I^{127}$	−0.60	5/2	$1d_{5/2}$ proton, $m_j = \|5/2\|$ negative Q
${}_{53}I^{129}$	−0.43	7/2	$1g_{7/2}$ proton, $m_j = \|7/2\|$ negative Q
${}_{54}Xe^{131}$	~0	3/2	$1d_{3/2}$ neutron, $m_j = \|3/2\|$ negative Q. or $3d_{3/2}$ neutrons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{57}La^{139}$	+0.20	7/2	$7g_{7/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \pm 5/2, \|7/2\|$ positive Q
${}_{63}Eu^{151}$	+1.20	5/2	$5d_{5/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \|5/2\|$ positive Q
${}_{63}Eu^{153}$	+2.50	5/2	$5d_{5/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \|5/2\|$ positive Q
${}_{70}Yb^{173}$	+3.9	5/2	$5f_{5/2}$ neutrons, $m_j = \pm 1/2, \pm 3/2, \|5/2\|$ positive Q
${}_{71}Lu^{175}$	+5.9	7/2	$3g_{7/2}$ protons, $m_j = \pm 1/2, \|7/2\|$ positive Q
${}_{71}Lu^{176}$	+7	$\geqslant 7$	$3g_{7/2}$ protons, $m_j = \pm 1/2, \|7/2\|$; $7f_{7/2}$ neutrons, $m_j = \pm 1/2, \pm 3/2, \pm 5/2, \|7/2\|$ } positive Q
${}_{73}Ta^{181}$	+6.0	7/2	$5g_{7/2}$ protons, $m_j = \pm 1/2, \pm 3/2, \|7/2\|$ positive Q
${}_{75}Re^{185}$	+2.8	5/2	$3d_{5/2}$ protons, $m_j = \pm 1/2, \|5/2\|$ positive Q
${}_{75}Re^{187}$	+2.6	5/2	$3d_{5/2}$ protons, $m_j = \pm 1/2, \|5/2\|$ positive Q
${}_{80}Hg^{201}$	+0.50	3/2	$3p_{3/2}$ neutrons, $m_j = \pm 1/2, \|3/2\|$ positive Q
${}_{83}Bi^{209}$	−0.40	9/2	$1h_{9/2}$ proton, $m_j = \|9/2\|$ negative Q

* The number in front of the angular momentum value of the nucleon state denotes the number of nucleons in this state, not the principal quantum number.

Xe^{131}, are in accord with the shell interpretation. It would appear also that apart from Q being dependent upon the distribution of nucleons among the m_j states, the magnitude of Q increases with increase of oscillator quantum number of the unfilled nucleon level.

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The Equation of State of Gaseous He^3

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August 16, 1949

Recent experiments[1,2] with pure He^3 show that it can be expected that in the near future measurements of the second virial coefficient $B(T)$ of the equation of state $PV = RT(1 + B/V + \cdots)$ will be available. In this connection it might be of interest to communicate briefly the results of a theoretical calculation of the second virial coefficient of He^3.

As the intermolecular forces, which are determined entirely by the electronic structure of the molecules, are the same in the cases He^3 and He^4, the second virial coefficients would be exactly equal in classical theory. In quantum theory, however, the second virial coefficients are not equal, because of the difference in de Broglie wave-length of He^3 and He^4 molecules to which must be added the influence of the fact that the wave functions in He^3 must be anti-symmetrical and those of He^4 symmetrical at permutation of the molecules.