3 Proceedings of the Bagnères Conference, 1953 (unpublished).

4 Armenteros, Barker, Butler, Cachon, and York, Phil. Mag. **43**, 597 (1952).

5 Buchanan, Cooper, Millar, and Newth (private communication). We are indebted to Dr. Newth for sending us a prepublication copy of this paper.

6 York, Leighton, and Bjornerud, Phys. Rev. **95**, 159 (1954). These authors report two groups of $V^{\pm}$ events. One group consists predominantly of a very short-lived positive particle with a probable two-body decay process and can be interpreted in terms of the hyperonic decay, $Y^{+}\rightarrow(\text{nucleon})^{+,0}+\pi^{0,+}$. The other group with a longer mean lifetime is concluded to be consistent, in every respect, with the decay process $K^{\pm}\rightarrow\mu^{\pm}+2$ light neutral particles ($M_K\sim 1000m_e$). From the consideration of lifetime, our data should be compared to the latter group in which York *et al.* do not report a charge asymmetry apart from a negative excess.

7 Thompson, Buskirk, Karzmark, and Rediker, Phys. Rev. **92**, 209 (1953).

8 Kim, Burwell, Cohn, Karzmark, and Thompson, Phys. Rev. **95**, 661 (1954).

9 In two events (R-112, R-390) the primaries are heavily ionizing and our mass estimates are consistent with the value of $1000m_e$. However, in all three events, the p_y values are high and p' is not very sensitive either to the primary mass or to whether the secondary is π or μ. The value of p' obtained in the present experiment may be used as a basis for calculation of the $K^{\pm}$ particle mass for various assumptions as to the nature of the decay fragments. The results are: $917\pm19m_e$ for ($\mu^{+}+\nu$ or γ), $948\pm18m_e$ for ($\pi^{+}+\nu$ or γ), $991\pm17m_e$ for ($\mu^{+}+\pi^{0}$), and $1022\pm17m_e$ for ($\pi^{+}+\pi^{0}$).

10 Gregory, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento **11**, 292 (1954).

11 A. L. Hodson *et al.*, post deadline paper, Washington Meeting of the Am. Phys. Soc. ,May, 1954.

12 Bridge, Courant, Dayton, DeStaebler, Rossi, Safford, and Willard (private communication). We are indebted to Dr. Bridge for sending us a prepublication copy of this paper.

13 Crussard, Kaplon, Klarmann, and Noon, Phys. Rev. **93**, 253 (1954), also Phys. Rev. **95**, 584 (1954). Report on the Padua Conference, 1954 (unpublished).

14 This point is further supported by the frequency of the ordinary τ decays observed in our chamber. We have observed only one τ^{+} decay.

15 Anderson, Cowan, Leighton, and van Lint, Phys. Rev. **92**, 1089 (1953).

16 The possible existence of a particle of mass about $1400m_e$ has been reported by D. H. Perkins and P. H. Fowler, Proceedings of the Duke Conference, 1953.

17 Such an example is reported in reference 5.

Alpha-Emitting Isomer Polonium 211†

W. Jentschke, A. C. Juveland, and G. H. Kinsey
University of Illinois, Urbana, Illinois
(Received August 9, 1954)

Spiess[1] has recently found that the α-particle bombardment of $_{82}Pb^{208}$ produces two short-lived α emitters belonging to $_{84}Po^{211}$, with $E_{\alpha}^{(1)}=7.14$ Mev, $T_{\frac{1}{2}}^{(1)}=25$ sec, and $E_{\alpha}^{(2)}=7.43$ Mev, $T_{\frac{1}{2}}^{(2)}=0.52$ sec. He concluded that these two states are isomeric states of $_{84}Po^{211}$, the 25-sec state being the ground state and the 0.52-sec state being an excited state having a low spin and an excitation energy of 0.3 Mev. He points out, however, that this explanation leads to a difficulty; in the K-capture decay $_{85}At^{211}\rightarrow{}_{84}Po^{211}$ only the 0.52-sec activity is observed. Since, according to shell theory, the ground state of both $_{84}Po^{211}$ and $_{85}At^{211}$ have spin 9/2, it is hard to understand why the 25-sec activity is not also found. Spiess also observed long-range α particles of low intensity, but did not identify them. We have investigated these long-range α particles and have shown that they are from $_{84}Po^{211}$. Our results lead to the revised decay scheme shown in Fig. 1. The 0.52-sec state appears as the ground state, and the difficulty mentioned by Spiess thus disappears. The 7.14-Mev α decay does not take place from the ground state of $_{84}Po^{211}$ but occurs from a 1.30-Mev 25-sec level and goes to the $i_{13/2}$ state of $_{82}Pb^{207}$.

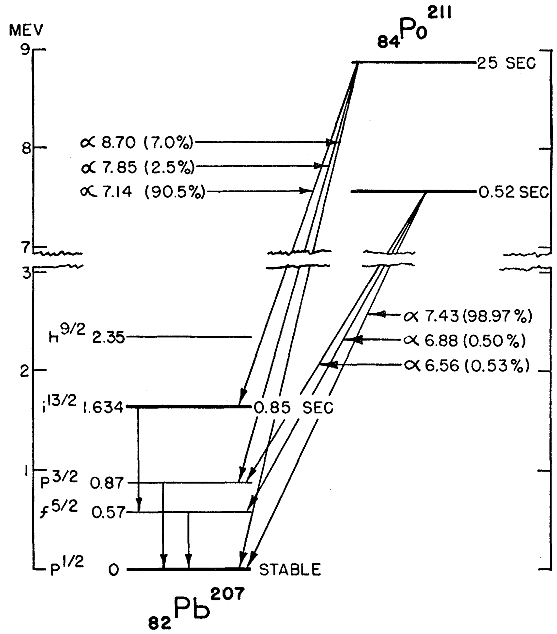

Fig. 1. Decay scheme of $_{84}Po^{211}$.

The decay scheme shown in Fig. 1 was deduced from the experiments 1–5 described below. In all of these experiments a thin lead foil was bombarded by α particles for 1 minute and measurements were started about 30 seconds after the end of the bombardment.

(1) The measurements of the energy of the α particles, made with an ionization chamber, gave peaks at 7.14 ± 0.05 Mev, 7.85 ± 0.05 Mev, and 8.70 ± 0.05 Mev. Figure 2 shows the pulse-height distribution. The differences in the α-disintegration energies: $8.87-7.28=1.59\pm0.07$ Mev and $8.87-8.00=0.87\pm0.07$ Mev agree with the excitation energies of the $i_{13/2}(E=1.63$ Mev) and the $p_{3/2}(E=0.87$ Mev) states of $_{82}Pb^{207}$.[2]

(2) The three α groups ($E=7.14$, 7.85, and 8.70 Mev) all have the same half-life of 25 sec. A fourth weak group at 6.58 ± 0.05 Mev decays with a half-life of about 2.1 minutes and probably belongs to $_{83}Bi^{211}$.

(3) The intensity ratios of the three groups remain unchanged while varying the bombarding α energy from 21.3 to 24 Mev, thereby changing the cross sections by a factor of about 3. These results indicate that all three groups are emitted from the same level of $_{84}Po^{211}$.

(4) γ-ray measurements with sodium iodide scin-

tillation counters showed the presence of a 0.56-Mev and a 1.06-Mev γ ray, both decaying with a half-life of 25 sec. The two γ rays are in coincidence.

(5) Since the half-life of the $i_{13/2}$ state of ${}_{82}Pb^{207}$ is 0.84 sec,[3] the 7.14-Mev alpha particles should not be in coincidence with γ rays. α–γ coincidence experiments with pulse-heights election confirmed this conclusion.

The absence of a 7.43-Mev α-peak in the pulse-height distribution indicates that the partial half-life of the γ transition from the 25-sec state to the 0.52-sec state is at least a hundred times as large as that for the α transition. From Weisskopf's formula[4] it follows that a transition with $L \geq 5$ is necessary to explain such a long half-life. According to shell theory, the 0.52-sec level should have a spin of 9/2. The 25-sec state then must have a spin of at least 19/2. This conclusion is also supported by α-decay considerations. Calculations of the α-decay half-lives, made using a semiempirical formula,[5] yield the result that spin changes of about 9,

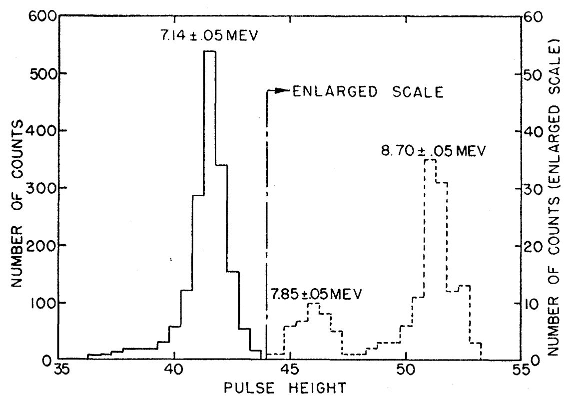

FIG. 2. Pulse-height distribution of the α particles from the 25-sec state of ${}_{84}Po^{211}$.

8, and 5 units accompany the 8.70, 7.85, and 7.14-Mev α decays of the 25-sec level and that the 7.43-Mev α decay occurs with a spin change of about 4 in agreement with the shell theory assignment of 9/2 for the spin of the 0.52-sec level. These results show that the spin of the 25-sec state very probably lies between 19/2 and about 23/2.

The simple single-particle model cannot explain the high spin of this excited state, since the highest reasonable spin for a low excited level of ${}_{84}Po^{211}$ would occur for the 127th neutron in a $j_{15/2}$ state. Spiess' suggestion that the excited state of ${}_{84}Po^{211}$ is due to "core isomerism"[6] is consistent with our decay scheme. By exciting the proton core to a $(h_{9/2}f_{7/2})$ configuration, and assuming the 127th neutron in the $g_{9/2}$ state,[7] the maximum spin of the 25-sec state would be 25/2.

It is somewhat surprising that the expected 25-sec α-particle group which decays to the $f_{5/2}$ state of ${}_{82}Pb^{207}$ could not be found. There seems to be some consistency, however, since the decay of the 0.52-sec level of ${}_{84}Po^{211}$ to the $f_{5/2}$ state of ${}_{82}Pb^{207}$ is also unexpectedly weak.[8]

According to these results the 8.70-Mev α particles decay with a partial half-life of about 360 sec from a state with a spin of at least 19/2 into a $p_{\frac{1}{2}}$ state. This is probably the largest spin change known for a nuclear decay.

The authors are grateful to Professor E. Segrè for suggesting this investigation. We thank Professor Hans Frauenfelder and Professor Peter Axel for valuable discussions and Mr. Sidney Singer for advice and help during the experiments.

† Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] F. N. Spiess, Phys. Rev. **94**, 1292 (1954).
[2] D. E. Alburger and M. H. L. Pryce, Phys. Rev. **95**, 1482 (1954). A. H. Wapstra, Arkiv Fysik **7**, 279 (1954).
[3] E. C. Campbell, Oak Ridge National Laboratory Report ORNL-1620, 1953 (unpublished).
[4] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).
[5] N. Feather, *Nuclear Stability Rules* (Cambridge University Press, London, 1952).
[6] M. Goldhaber, Phys. Rev. **89**, 1146 (1953).
[7] Fred, Tomkins, and Barnes, Phys. Rev. **92**, 1324 (1953).
[8] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

Vacuum Polarization in a Strong Coulomb Field*

EYVIND WICHMANN AND NORMAN M. KROLL
Columbia University, New York, New York
(Received August 17, 1954)

IN the interpretation of recent experiments with x-rays from μ-mesonic atoms, some reference has been made to the role of vacuum polarization both in connection with the μ-mass determination[1] and in connection with nuclear radius determinations.[2–5] The estimates made have been based on the Uehling formula,[6] which is merely the first term of an expansion in powers of αZ. Since the experiments have been carried out in elements as heavy as lead, for which $\alpha Z = 0.6$, the role of higher-order corrections may be significant.

Another situation in which such effects may play an experimentally significant role is in connection with the x-ray fine-structure separation $(2P_{\frac{1}{2}} - 2P_{\frac{3}{2}})$ in the heavy elements. The large value of the nuclear radius deduced by Schawlow and Townes[7] from the anomalous Z dependence of this fine structure might be brought into agreement with values determined by other methods by including electrodynamic effects. One must in this case, of course, include the effects of the mass operator as well as those of the polarization charge.

There is, of course, also some general theoretical interest in the treatment of such quantities, by techniques which either avoid power series expansions in certain quantities, usually treated as small, or which establish the convergence of these power series. Ac-