currents in the liquid. Another interesting possibility arising from the rapid bubble growth is that one could take multiple exposure photographs of events so that a measurement of bubble size could tell the relative ages of tracks in the range 0 to 100 microseconds. It should be possible to construct larger bubble chambers, to use liquids of various composition and density, and to calibrate the bubble density along a track in relation to the ionization density.

In order to estimate the conditions under which a bubble chamber will be useful as a detector of ionizing radiation, and to guide the choice of a working liquid, an approximate theory of the stability of charged bubbles in superheated liquids has been developed. To understand the result let us first suppose that as a result of thermal fluctuations a tiny spherical bubble at least several molecular diameters across is formed in the liquid and that a single ion is made inside the bubble by an ionizing event. It is easy to show that the ion will run to the surface of the bubble, and that the energy contribution of its electric field is such as to encourage the collapse of the bubble. If, on the other hand, the bubble contains a number of ions, they will distribute themselves roughly uniformly over the surface and aid its growth. When only two or three ions are present, the result is not clear cut, and depends on the detailed shape of the bubble and the mechanism by which the ions are prevented from escaping into the bulk of the liquid.

The main result of the theory, in the continuously distributed charge approximation, is that for a bubble carrying n charged ions to grow to visible size, the liquid must be superheated so that the normal saturated vapor pressure p_∞ exceeds the actual applied pressure on the system by the amount

$$p_n(T)=3/2\left(\frac{4\pi}{n^2e^2}\right)^{1/3}[\sigma(T)]^{4/3}[\epsilon(T)]^{1/3}. \tag{1}$$

This result neglects the dependence of the surface tension σ and dielectric constant ϵ on the curvature of the surface and on the pressure.

To find the temperature at which a bubble chamber will operate, one plots $p_n(T)$ and $p_\infty(T)$ *versus* T on the same graph. The intersections for the various n give the required temperatures and pressures. For diethyl ether the predicted and measured temperatures are closer than 10°C if n is something between 2 and 10.

If ionizing radiation is the limiting factor in an experimental attempt to obtain high superheats in pure liquids, one would expect the present theory to predict maximum attainable superheats. For the few liquids for which good data are available the agreement is within 20°C or better.

In its broad outlines this analysis parallels that of droplet growth in a supersaturated atmosphere. The present multiple-charge modification extends the effect so that ionizing events can make a growth-aiding contribution to the surface free energy of a particle of new phase in any nucleation situation in which the two phases have a difference of dielectric constant. This fact may have interesting consequences for the influence of ionizing radiation on nucleation in supercooled liquids, supersaturated solutions, etc.

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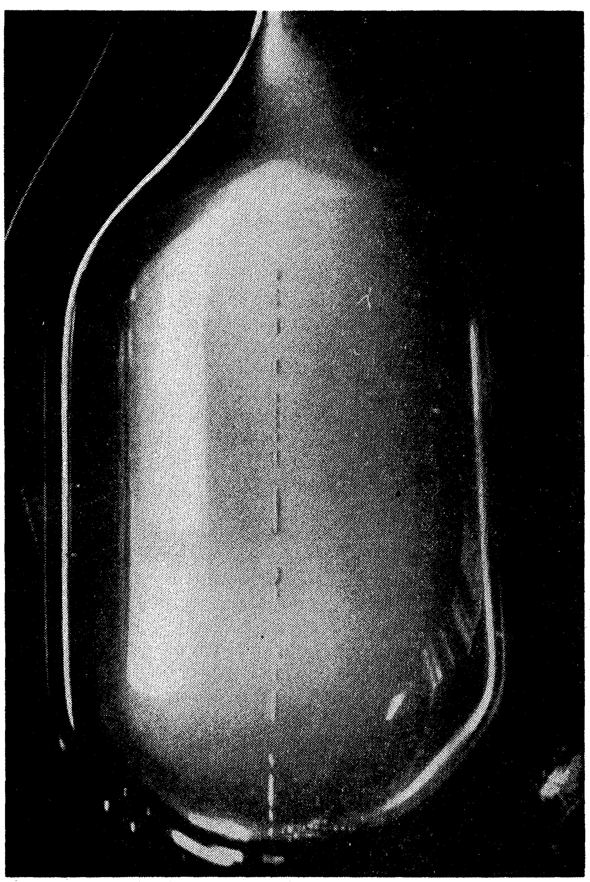

FIG. 2. duration 5 microseconds, no deliberate delay, temperature 141°C.

Patterns in Alpha Spectra of Even-Even Nuclei

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THE present communication aims to bring out some definite regularities in the spectra of even-even alpha emitters without elaborating particularly on the possible significance of these findings regarding alpha-decay theory and spectroscopic states of heavy nuclei. Most of the data to be discussed were obtained over the range of elements from curium 96 to radium 88 since it is inherently difficult to make the necessary measurements for elements below radium.

We shall first suggest some means to identify the energy states which seem to recur generally and to designate the alpha transitions leading to these states. The first rule for even-even alpha emitters is that the most prominent alpha group leads to the ground state of the product nucleus as would be expected from previous alpha-decay theory. (This is not the case for nuclear types having odd nucleons.) In addition, an alpha group is invariably found which leads to a level with spin 2 and even parity, and the abundance of this group likewise conforms in first approximation with the expectations from unadorned alpha-decay theory. The energy level of this excited state will be termed the *first even-spin state* and lies about 40 kev above the ground state at plutonium, increasing with decreasing mass number as already described.[1,2] In low abundance are found alpha groups leading to other levels which we shall term *second and third even-spin states.* In the few cases for which gamma-ray data are available it seems probable that these levels have even parity as well as even spin and may very well be 4+ and 6+ states. There is some fragmentary evidence in our work that an odd-spin odd-parity state is appearing in a limited region, but this will not be discussed further at present.

Bohr and Mottelson[3] have suggested that nuclides well beyond a closed shell have states in which the nucleus acts as a rigid rotator. The energy of such rotational levels should be proportional to $J(J+1)$, where J is the total angular momentum quantum number. If we consider the 2+ and 4+ states to be rotational states, the ratio of the energies should be 3.3. Figure 1 shows

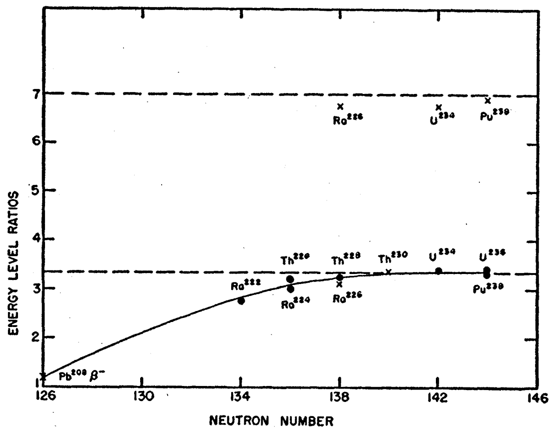

FIG. 1. Energy ratios for the levels of even-even nuclides. ● From alpha-particle spectrograph data. × From gamma-ray data.

experimental ratios for 10 nuclei in the heavy element region plotted against neutron number. It is fairly certain that corresponding states are compared here although in only one case, Cm^{242}, have the necessary measurements been made to establish this state as 4+.[4] The heaviest nuclei show remarkably close agreement with the expectations for the postulated rotational states and there appears to be a progressive departure from the ratio 3.3 toward lighter nuclei. (There is no convincing justification for plotting these data strictly with respect to neutron number as is done here; in fact, it is not to be expected that the nuclear deformation which defines these levels is simply a function of the neutron number.)

Gamma-ray data have been used to infer the existence of the third *even-spin* state for three species. The ratios of the third to

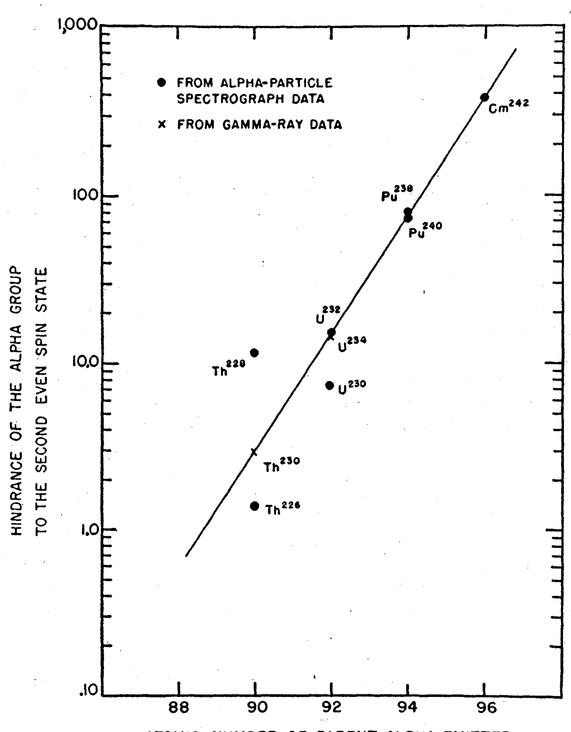

FIG. 2. Relation between the observed partial half-life and that calculated from alpha-decay theory for the alpha group populating the second even-spin state.

the first levels are indicated in Fig. 1 in relation to the theoretical value 7 for the third rotational state, $J=6$.

In the study of the alpha spectra of most of the nuclides shown in Fig. 1, it became clear that the alpha transitions leading to the second even-spin states were highly hindered. That is, the measured partial half-lives were much longer than expected simply from the energy and nuclear charge. (It will be remembered that the ground-state transitions and those leading to the first even-spin states are in first approximation unhindered.) The Cm^{242} alpha group leading to the second even-spin state, as an example, has a half-life almost *400-fold longer* than expected from theory. On examining this relationship for alpha emitters of lower elements, it was found that as the energy of the second even-spin state increased, the hindrance factor decreased. For the species examined so far, the logarithm of the hindrance factor varies linearly with the atomic number (Fig. 2). There is no quantitative explanation yet known for the close agreement of this function. (It will be noted that a few points lie off the curve.)

If we assume that the same spin change is involved in each of these transitions, an explanation cannot lie in simple fashion in this direction both because of the large hindrance factors in some cases and because of the wide variation. A possible explanation lies in the assumption of a progressive change in charge asymmetry on leaving the closed shells in the vicinity of lead. The potential barrier will then be spherically nonsymmetrical and if the alpha particles of a type have a preferred direction of emission, any progressive change in charge distribution will be reflected in a progressive change in the ease with which the alpha particle can leave.

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[2] S. Rosenblum and M. Valadares, Compt. rend. **235**, 711 (1952).
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High Altitude Measurements of the Intensity of Cosmic Radiation at Magnetic Latitudes 3°N and 19°N

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THE total intensity and penetrating component of cosmic radiation in the vertical direction have been measured as a function of altitude at Bangalore, magnetic latitude 3°N, and Delhi, magnetic latitude 19°N, during the years 1951–1953. Quadruple coincidence G.M. counter telescopes without any absorber and with 10 cm of lead absorber in between the counter trays were sent up in free balloon ascents to measure the total intensity and that of the penetrating component, respectively. The geometry of the telescopes was so designed that the most inclined particle recorded by the telescopes would only traverse a thickness of the atmosphere and the absorber 10 percent greater than a particle arriving vertically. The half-angles of the telescopes about the vertical were 13.5° and 24.5°. The temperature inside the gondola which contained the apparatus was maintained between +15°C and +25°C by using the greenhouse effect. The atmospheric pressure and temperature inside the gondola were measured by an aneroid and bi-metallic strip meteorograph of the Olland type. A mercury manometer was also used as an independent check on the pressure measurements. The atmospheric pressure, temperature inside the gondola, and the cosmic-ray data, were transmitted to the ground receiving station where they were recorded automatically on a moving paper tape.

The results obtained at the two stations Bangalore and Delhi are given in Fig. 1 as intensity *vs* pressure curves. Curves A^1 and B give the penetrating component at 3°N and 19°N, respectively, and C and D the total intensities at the above two latitudes. Every curve in the figure is a composite curve of the data obtained in a number of flights. The root-mean-square deviations of the points are marked for each curve.