

scheme, while those transitions shown account for the β - γ and γ - γ coincidence results described above. Either one or both of the 42.6- and 37-kev levels is probably metastable.

¹ Detailed examination, by means of proportional counters of the form of the β -spectrum, is described by Insch, Balfour, and Curran of this Department, in a paper to be published in *The Physical Review*.

² N. Feather, *Nucleonics* 5, No. 1, 22 (1949).

³ L. Cranberg, *Phys. Rev.* 77, 155 (1950).

⁴ Frilley, Gokhale, and Valadares, *Compt. rend.* 232, 50 (1951); 232, 179 (1951).

⁵ D. K. Butt and W. D. Brodie, *Proc. Phys. Soc. (London)* 64, 791 (1951).

⁶ Curran, Angus, and Cockroft, *Phil. Mag.* 40, 36 (1949).

⁷ *Nuclear Data*, National Bureau of Standards Circular No. 499 (1950).

⁸ H. O. W. Richardson and A. Leigh-Smith, *Proc. Roy. Soc. (London)* A160, 454 (1937).

⁹ Bannerman, Lewis, and Curran, *Phil. Mag.* 42, 1097 (1951).

Information and Thermodynamics

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THE connection between information as defined in communication theory and statistical entropy (essentially negative or missing information) has been clarified by the measurement-communication analogy,¹ leading to the following statements which include the second law. Our information about an isolated system can never increase (only by measurement, i.e., interaction with the system, can new information be obtained). Reversible processes conserve information, irreversible ones lose it. Theoretically maximal information, corresponding to a pure state, has zero entropy; minimal information, corresponding to equilibrium, has maximum entropy. If one considers measuring apparatus and system of interest as a compound isolated system, then by the first statement information (obtained by measurement) is amply compensated by entropy increase in the compound system, no measurement is possible for equilibrium between the two parts, and the positive time direction can be taken equally as that corresponding to entropy increase of the compound system or of information increase regarding the system of interest. The last is closer to psychological or subjective time and also corresponds to time measurement (clock is object of interest). Past and future are symmetrical for equilibrium and for the purely mechanical case (zero entropy, pure case; note use of mechanical to include electrical, magnetic, etc., classical or quantal).

Consider now the informational interpretation of the first law and of quantity of heat. The first law can be expressed by mechanical concepts (in the general sense) alone, with quantity of heat then defined by the conservation of energy.² The first law asserts the existence of a state energy function, *viz.*: to bring a system adiabatically (i.e., via well-defined mechanical operations) from a definite initial state to a definite final state requires the same amount of mechanical work independently of the sequence of intermediate states. The state function U so defined (energy) is fixed to within an additive constant; for adiabatic change from state 1 to state 2,

$$U_2 - U_1 = \int_1^2 dW. \quad (1)$$

The quantity of heat given a body going from 1 to 2 over a specific, not necessarily adiabatic, path is now defined by

$$\int_1^2 dQ = (U_2 - U_1) - \int_1^2 dW. \quad (2)$$

From an information viewpoint quantity of heat is thus energy transferred in a manner which has eluded mechanical description, about which information is lacking in terms of mechanical categories. Adiabatic changes make (2) vanish and thus for heat to be transferred the path must contain states which cannot be reached adiabatically from the initial state. Applied to (2) in differential form, namely

$$dQ = dU - dW, \quad (3)$$

the existence of adiabatically inaccessible states in the neighborhood of a given state follows. But this is precisely Caratheodory's principle, from which the existence of an integrating denominator for the Pfaffian (3) then follows, and from which in turn absolute temperature and the entropy function can be derived. It is noteworthy that even if the informational or statistical interpretation of entropy were not at hand, the first law with quantity of heat informationally characterized as above would lead to it. For all states adiabatically accessible (equivalent informationally) from a given state would generate a "surface" which would be a member of a one-parameter family. The value of the parameter would be a measure of missing information relative to some standard state; the parameter can be shown to be a function of the entropy only.

To sum up, the laws of thermodynamics can be stated as:

(a) The conservation of energy.

(b) The existence of modes of energy transfer incapable of mechanical description.

In a sense (b) is implied in (a), for (a) without (b) is a mechanical theorem devoid of thermodynamic content.

(c) The third law is true by definition, for in a perfectly ordered state at absolute zero there is no missing information, i.e., the entropy is zero (pure case).

¹ J. Rothstein, *Science* 114, 171 (1951) and references cited.

² A. Landé, *Handbuch der Physik* (J. Springer, Berlin, 1926), Vol. IX, Chapter IV gives this formulation of the first law and a readable account of Caratheodory's axiomatic formulation of thermodynamics.

Slow Neutron Fission of Am^{242} , Am^{242m} , and Am^{243*}

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THIS letter is to report the pertinent results of some work which was done at scattered intervals during the years 1947 to 1949 and which may now be published. Independent measurements of the same cross sections by a Canadian team¹ gave somewhat different results.

Shortly after the discovery² of Am^{242} in a sample of Am^{241} irradiated with pile neutrons, it became apparent that this nuclide had a large destruction cross section. In a second Am^{241} irradiation of three times the intensity of the first, only 1.4 times as much Am^{242} was formed as determined³ by counting the beta-particles of Am^{242} . This ratio gave a destruction cross section for Am^{242} of approximately 10^4 barns. (This result is very insensitive to the cross section for the formation of Am^{242} as long as it is much less than 10^4 barns.) That this destruction was at least partially due to neutron capture to form Am^{243} became apparent with the discovery of this nuclide.³

When a mass spectrographic analysis of this second americium sample became available in December, 1949, it was possible to estimate the distribution of the destruction cross section of Am^{242} between fission and neutron capture to form Am^{243} . The composition of the americium was shown to be Am^{241} (99 percent), Am^{242} (0.5 percent), and Am^{243} (0.5 percent). From these data one calculates the following approximate cross sections: cross section for the formation of Am^{242} , ~ 50 barns; neutron capture cross section of Am^{242} to form Am^{243} , ~ 2000 barns; and total cross section for the destruction of Am^{242} , ~ 8000 barns. Thus the fission cross section of Am^{242} must be ~ 6000 barns. The estimate of 2000 barns for the cross section of the reaction $\text{Am}^{242}(n, \gamma)\text{Am}^{243}$ is somewhat smaller than a previous estimate³ and is still subject to large errors. The principal uncertainties are in the estimation of the neutron flux.

In 1949 the fissionability of americium samples containing various amounts of the nuclides Am^{242} and Am^{243} was measured with a fission counter⁴ in the thermal neutron column of the Argonne heavy water pile. Measurements on americium of the composition given above gave a fission cross section for Am^{242} of

about 6000 barns in agreement with the value obtained above. The measured fissionability was corrected for the Am^{241} present ($\sigma_{\text{fission}} 3.0$ barns).^{1,5} The fact that the Am^{243} present contributes a completely negligible amount to the observed fission was demonstrated by measuring an americium sample containing very nearly the same amount of Am^{242} and more than ten times as much Am^{243} . The observed fissionability in this sample was accounted for by the Am^{242} and allows a limit of less than 40 barns to be set on the fission cross section of Am^{243} .

The recent observation of the isomeric transition from the 16-hour Am^{242m} to the ground state⁶ makes it seem likely that the Am^{242} observed in these samples came mainly through the formation of Am^{242m} and its subsequent decay to the ground state. Taking the branching of 20 percent given by O'Kelley *et al.*,⁶ and a cross section of ~ 300 barns⁷ for the formation of Am^{242m} , the apparent cross section for the formation of Am^{242} in long irradiations (i.e., $\gg 16$ hours) is about 60 barns, in fair agreement with that calculated from the isotopic abundances.

Some old measurements from this laboratory on the fissionability of Am^{242m} should be reinterpreted in the light of the isomeric transition to the highly fissionable Am^{242} . In this old work it was found that the fissionability of a sample of Am^{241} containing 50 parts per million of Am^{242m} (the amount of Am^{242m} was determined by counting the Cm^{242} which grew in and has been corrected for 60 percent beta-decay branching)⁶ decayed with a 16-hour half-life to the extent of 2.1 percent. Using these data and taking the fission cross section of Am^{241} as 3.0 barns, the fission cross section of Am^{242} as 6000 barns, and the branching decay of Am^{242m} by isomeric transition as 20 percent, one obtains a fission cross section for Am^{242m} of about 2000 barns for thermal column neutrons. Again this value is subject to large errors.

We would like to express our appreciation to W. H. Zinn for the use of facilities at the Argonne National Laboratory for making the fission measurements. We also wish to thank Professor Glenn T. Seaborg for his continued interest and advice.

* This work was performed under the auspices of the AEC.

¹ Hanna, Harvey, Moss, and Tunnicliffe, *Phys. Rev.* **81**, 893 (1951).

² Seaborg, James, and Morgan, National Nuclear Energy Series, Plutonium Project Record, Vol. 14B, *The Transuranium Elements: Research Papers*, Paper No. 22.1 (McGraw-Hill Book Company, Inc., New York, 1949).

³ Street, Ghiorso, and Seaborg, *Phys. Rev.* **79**, 530 (1950).

⁴ A. Ghiorso and W. C. Bentley, National Nuclear Energy Series, Plutonium Project Record, Vol. 14B, *The Transuranium Elements: Research Papers*, Paper No. 22.29 (McGraw-Hill Book Company, Inc., New York, 1949).

⁵ B. B. Cunningham and A. Ghiorso, *Phys. Rev.* **82**, 558 (1951).

⁶ O'Kelley, Barton, Crane, and Perlman, *Phys. Rev.* **80**, 293 (1950).

⁷ Obtained from an observed cross section of 200 barns for the formation of Cm^{242} and 60 percent beta-decay branching of Am^{242m} .

Light Emission from Silicon Carbide

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THE following observations, made some years ago, seem worth recording in view of the recent paper by Lehovc, Accardo, and Jamgochian.¹

Various crystals found on silicon carbide "pig" having two roughly parallel plane faces were arranged with a "point" contact on one of the faces and another contact elsewhere on the lump of pig to which the crystal was attached (a large area contact to the crystal itself would presumably have served equally well for the latter). The region of the point contact was viewed through the opposite face, and it was seen that the primary source of light is a very small bright region at the contact, of a color like that of the crystal viewed by transmitted light. If one looks through the face of the crystal to which the point contact is made, however, as indicated in Fig. 1 of reference 1, this primary source of light is always eclipsed by the contact wire itself, and a much less intense light from a much larger volume is seen. This

appears to be merely scattered and internally reflected light from the now invisible primary source, and its characteristics are modified by both scattering and absorption.

To make observations of spectral distribution which can be interpreted with any certainty, it seems very desirable to look at the contact region through a different face from that to which contact is made, and to make independent measurements of absorption characteristics between these faces, remembering that some crystals vary considerably from one region to another.

Because of the high refractive index of silicon carbide, the contact must lie almost on a normal to the viewing face, otherwise it cannot be seen directly; also the crystal, if deeply colored, must be very thin. Satisfactory crystals are not common, and it may be preferable to obtain specimens by grinding and polishing.

¹ Lehovc, Accardo, and Jamgochian, *Phys. Rev.* **83**, 603 (1951).

The Production of Halogen Negative Ions at the Surface of a Thoriated Tungsten Filament*

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BY directing molecular beams of cesium halides at a hot thoriated W wire we have been able to obtain large percentage yields, as shown in Table I, in the production of some of the halogen negative ions. The percentage yield is defined as the ratio of halogen negative ion current from the activated wire to the cesium positive ion current from the deactivated wire. If the dissociation of the molecule into atoms is complete on the surface, then the Cs ion current is equal to more than 99 percent of the incident, neutral beam current.

Because of the relatively high pressure, of the order of 10^{-6} mm Hg, in the apparatus, electron emission and negative ion yield decreased from maximum values obtained immediately after activation of the wire to stable values which remained constant for long periods of time. Although the cesium positive ion current densities at the hot wire were large, around 5×10^{-6} amp/cm², there was no indication that either electron emission or negative ion yield was affected by prolonged "irradiation" by the beam.

At an early stage in the work negative ions from the activated wire were analyzed with a mass spectrometer and found to be halogen ions. No trace of molecular ions was discovered. For the yield measurements presented here a special electrode arrangement was constructed such that with appropriate potentials all charged particles of one sign leaving the wire could be directed through a system of slits into a collecting cup connected to a galvanometer. The fringing field of a strong permanent magnet located outside the apparatus was used to keep electrons from striking the collector. However, the residual electron current was large enough to prevent measurements of ion yields less than 1 percent.

For wire temperatures in the range from 1200°K to 1500°K no substantial change in negative ion yield was observed. Below 1200°K the ion current dropped sharply to zero. Above 1500°K residual electron currents were too large to permit measurements.

We feel that the negative ions are produced by the process of surface ionization rather than by electron capture in the region outside the hot wire because, (1) the negative ion yield was nearly independent of electron emission from the activated wire, and

TABLE I. Halogen negative ion yields.

Beam material	Maximum yield: percent	Stable yield: percent
CsI	4	2
CsBr	20	11
CsCl	60	30
CsF	<1	—