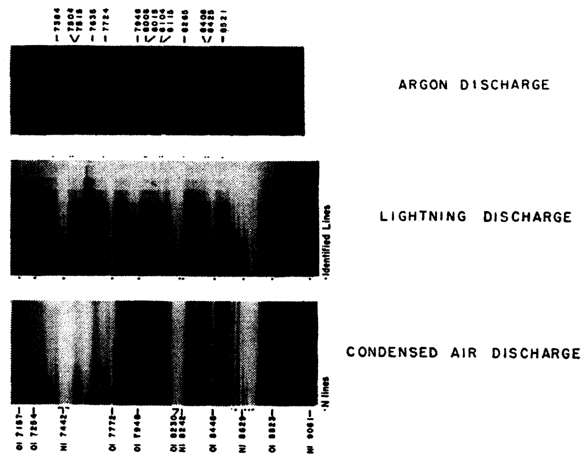

FIG. 1. The infrared spectrum of lightning.

of our auroral spectrographs, the optics of which consist of a mirror collimator, a plane grating, and an f0.8 flat field Schmidt camera. The linear dispersion of the instrument is approximately 85 angstroms/mm in the first-order spectrum. The spectrum recorded is the result of many flashes from a storm which lasted about one hour.

Figure 1 shows the lightning spectrum (a step-slit was used) and for comparison the spectra of argon and a condensed discharge through air. The latter spectra were produced by a grating instrument which has a dispersion of approximately twice that of the auroral spectrograph, and hence by varying the magnification, it has been possible to match reasonably well similar wavelength regions on the three prints.

TABLE I. Wavelengths of infrared lightning spectral features.

Wavelength	Identification	Excitation potential
7157	O I $^1D^0-^1D$	14.40
7217	···	
7254	O I $^3P-^3S^0$	12.64
7267	···	···
7280	···	···
7384	A I	···
7424 7442 7468	N I $^4P-^4S^0$	11.94
7504	A I	13.42
7515	A I	···
7550	···	···
7724	A I	13.10
7761	···	···
7772	O I $^5S^0-^5P$	10.69
7862	···	···
7891	A I	···
7901	···	···
7918	···	···
7948	O I $^3D^0-^3F$	14.04
8005	A I	13.11
8015	A I	13.04
8104	A I	13.10
8115	A I	13.02
8185 8188 8210	N I $^4P-^4P^0$	11.79
8216 8223 8242	N I $^4P-^4P^0$	11.79
8265	A I	13.27
8408	A I	13.24
8425	A I	13.24
8446	O I $^3S^0-^3P$	10.94
8521	A I	13.23
8568 8594 8629 8656	N I $^2P-^2P^0$	12.07
8680 8683 8686 8703 8712 8719 8729 8747	N I $^4P-^4D^0$	11.70
8820	O I $^1D^0-^1F$	14.07
9041	···	···
9061	N I $^2S^0-^2P$ C I $^3P^0-^3P$	12.91 8.81
9078	C I $^3P^0-^3P$	8.81

The wavelengths and identifications of the spectral features, and the excitation potentials of the upper energy levels from which these radiations originate, are given in Table I.

It is interesting to note the complete absence of molecular radiations; all the spectral features are atomic in origin. Furthermore, all radiations are from neutral atoms. The same result has been found by José.[1] The most intense argon lines in the wavelength region 7300–8500 angstroms are present in the lightning spectrum as they are in the spectrum of the air discharge. This is evidently the first identification of argon lines in the spectrum of the atmosphere above the earth's surface. A portion of the low level C I multiplet $^3P^0-^3P$ appears to be a feature of the spectrum. It is our intention to compute excitation temperatures from the intensities of the N I and O I lines; these data will yield information on the energy in the lightning discharge.

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The Binding Energy of Four Neutrons in U^{239} and the Disintegration Energies of U^{239} and Np^{239}

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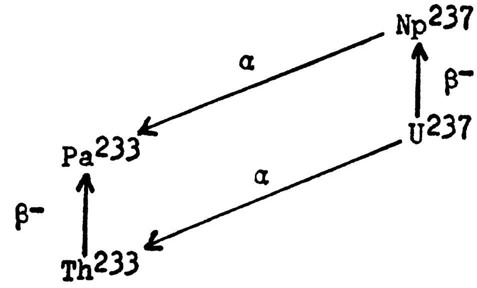
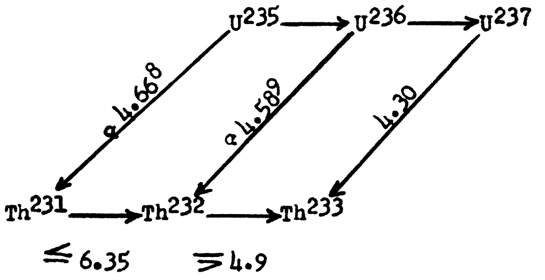
FROM the recent measurements of the binding energy of a neutron in U^{239}, U^{238}, Th^{233}, and Th^{232} and the alpha-energies of U^{235}, U^{236}, and U^{237}, it is possible to calculate the binding energy[1–4] of four neutrons in U^{239}. The alpha-energy of U^{237} is estimated from alpha-systematics.[5] This value can also be derived from the following cycle.



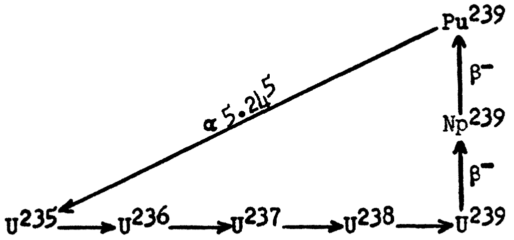
Recent measurements on the total decay energy of Th^{233} [6,7] and U^{237} [7] give a calculated α-energy for U^{237} in agreement with systematics.

The binding energy of a neutron in U^{237} and U^{236} is calculated from the following cycles. The binding energy



of four neutrons in U^{239} is found to be 22.21 Mev by summing the binding energies of one neutron in U^{239} (≥ 4.63), U^{238} (≤ 5.97), U^{237} (≥ 5.18), and U^{236} (≤ 6.43).

The sum of the disintegration energies of U^{239} and Np^{239} can be calculated from the following cycle with the aforenamed data and the α-disintegration energy of Pu^{239}.



$$
\begin{aligned}
E_{\beta\beta} &= [\text{Mass }(4n\text{'s}) - \text{Mass }(\mathrm{He}^4)] - E_\alpha\ (\mathrm{Pu}^{239}) - \text{binding energy of } 4n\text{'s in } \mathrm{U}^{239} \\
&= \quad 29.79^{10} \qquad -5.24 \qquad -22.21 \\
E_{\beta\beta} &= \quad 2.34 \text{ Mev.}
\end{aligned}
$$

Slätis[11] has proposed a decay scheme for U^{239} of total disintegration energy 2.06 Mev, including a 2.06-Mev beta in 3 percent abundance and 0.9-Mev and 0.073-Mev gammas in cascade with a 1.12-Mev beta. For Np^{239} he reports a beta-component of 1.181 Mev in 1 percent abundance leading to the ground state of Pu^{239}, together with betas of 0.678, 0.406, and 0.288 Mev, and suggests a decay scheme including 7 observed gammas. Thus a double decay energy $E_{\beta\beta}$ of 3.24 Mev follows.

The apparent discrepancy with the aforementioned calculation led us to reexamine the beta-spectra of U^{239} and Np^{239}. By employing a very active sample of U^{239} prepared by neutron irradiation of depleted U^{238} and radiochemically separated from fission products, in our double lens spectrometer we establish an upper limit of 0.02 percent on the abundance of a 2-Mev beta. A thinner sample was used to measure the main beta for which we find an energy of 1.22 Mev. On a scintillation spectrometer we observe only the prominent *ca* 0.075-Mev gamma; the 0.9-Mev gamma, if present, has a relative intensity of less than 1 percent. Thus the spectrum appears to be simple, with a total disintegration energy of 1.295 Mev.

The beta- and gamma-spectra of Np^{239} have recently been carefully examined by Graham and Bell[12] who by spectrometer coincidence techniques show that the 705-kev beta has no gammas in sequence, and by Tomlinson *et al.*,[13] who find, in a high resolution spectrometer, betas of 0.715, 0.654, 0.44, and 0.33 Mev, and 88 conversion lines assigned to 11 gammas. We examined a very intense sample of Np^{239} for hard betas and report a maximum relative abundance of 0.01 percent for betas of greater than 0.72 Mev. A second spectrum on a thin sample (<0.1 mg/cm²) disclosed 45 conversion lines above 10 kev and four beta-components, in essentially complete agreement with the results of reference 13. Thus the beta of 0.715 Mev is probably correctly assigned to the ground state transition,[12] and the double beta-decay energy is then 2.01 Mev. This value is 0.33 Mev less than the value calculated with the aid of the binding energy of four neutrons in U^{239}. Some of this discrepancy may be caused by the uncertainty in the mass difference of four neutrons and helium. There is also some possibility of a weak γ (*ca* 0.05 Mev) in cascade with the Pu^{239} alpha-particle.[5] Since the experimental disintegration energies of Np^{239} and U^{239} are probably more accurate than the experimental binding energies, the binding energy of four neutrons in U^{239} may be too small by about 0.3 Mev.

TABLE I. Neutron binding energies

Isotope	Neutron binding energy (Mev) measured by (d, p)	(γ, n)	Neutron binding energy (Mev)[d]
92^{238}	...	5.97 ±0.1[b]	≤5.97
92^{239}	4.63 ±0.15[a]	...	≥4.63
90^{232}	...	6.35 ±0.1[c]	≤6.35
90^{233}	4.9 ±0.2[a]	...	≥4.9

See reference 1. [b] See reference 2. [c] See reference 3. [d] See reference 4

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