each in V_g[b] and V_f[c]. These terms have their origins in the more difficult and subtle questions connected with auxiliary conditions. In one development of these interactions by the writer they do not appear at all. In another they are replaced by innocuous terms. It must be noted that the uniform introduction of the factor $a\kappa$ in all coupling constants or the equivalent device commonly employed,[5] while giving interactions which satisfy tests II and III, is not permissible according to test I. In particular the Newtonian and Coulombian static fields then are lost in the limit of zero-meson mass.

Assuming tentatively that the pi-meson is the principal nuclear force meson then $(a\kappa)^2=(m/M)^2\sim 1/40$. We come then to the important physical conclusion that only if the fine structure constants (α_p for pole coupling and α_d for dipole coupling) are related by $\alpha_d\sim 40\alpha_p$ will the static interactions arising from dipole coupling be of the same order of magnitude as the static pole interaction. Since α_d is then greater than one we are forced to strong coupling for this part of the interaction. On the other hand if we assume $\alpha_d\sim\alpha_p$ we find that the effects of dipole coupling are small compared to the static pole interactions and, in fact, are of the same order of magnitude as the relativistic pole interactions. Thus the assumption of simultaneous pole and dipole coupling is an undesirable complication. Indeed, the complication is even greater than indicated by Kemmer's treatment which does not bring out the pole-dipole interference terms and which discards contact interactions.[6] We can, nevertheless, utilize the Kemmerian interactions, with the suggested modifications, by regarding them as eight distinct interactions four of which, the pole cases, have a more elementary nature. Three of these cases, the scalar-scalar, the vector-vector and the pseudovector-pseudovector[7] have large static terms, but they are not promising nuclear interactions. The pseudoscalar-pseudoscalar, a synthesis of the first two,[8] and the four dipole cases give rise to more interesting interactions which, however, are too small in the case of a one-meson field for $\alpha<1$. In a later communication we shall discuss the possibility that these latter interactions, in conjunction with a generalized multiple-meson field, may contain the correct nuclear interaction.

[1] A. Green, Phys. Rev. **75**, 1926 (1949).
[2] E. Wigner, Phys. Rev. **51**, 106 (1937).
[3] N. Kemmer, Proc. Roy. Soc. **A166**, 145 (1938). As usual the factor $c\kappa/4\pi$ has been removed and we consider for convenience the neutral theory.
[4] Admittedly a factor 2π would nullify some of the ensuing arguments.
[5] G. Wentzel, Rev. Mod. Phys. **19**, 3 (1947), Eqs. (1) and (2).
[6] L. Van Hove, Phys. Rev. **75**, 1519 (1949).
[7] For some treatments of the auxiliary conditions.
[8] A. Green, Phys. Rev. **76**, 460 (1949).

Mass Assignment of Xenon Activities Produced in Fission

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THE electromagnetic isotope separator[1] of this Institute has been used in order to ascertain the mass-numbers of the Xe isotopes produced in fission. The gaseous fission products from neutron irradiated uranium oxide were fed to the ion source and the active isotopes collected on a thin aluminium plate. This method has recently been used by J. Koch, Copenhagen, in an investigation of the Kr isotopes produced in fission (private communication). The method of determining the mass numbers, corresponding to the different activities, was the same as used for the mass assignment of 43^m Hg^{199} [2] and 53^d Hg^{203}.[1]

TABLE I. Summary of results.

Element	Mass number	Half-life	Parent isotope (according to Seaborg's tables and our measurements)
Xe	133	~5.4 d	
Xe	135	9.1 hr.	
Xe	137	3.5 min.	I^{137} 22.0 sec.
Xe+Cs	138	30.0 min.	I^{138} 5.9 sec.

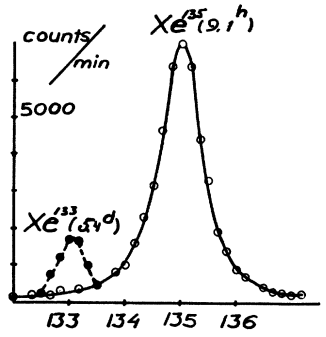

FIG. 1a. The activity of the 5.4 d and 9.1 hr. xenon isotopes. Dotted curve is the 5.4 d activity, measured 3 days after the 9.4 hr. activity and drawn to a 5 times larger scale.

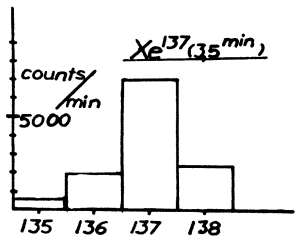

FIG. 1b. The activity of the 3.5 min. Xe isotope measured immediately after separation and 8 minutes after stopping the cyclotron.

Figures 1a, b, and c show the measured activity as a function of the position on the collector plate and the results are summarized in Table I. This confirms that the assignments of these isotopes in Seaborg's tables[3] are correct (the mass numbers 137 and 138 were classified as *B* and *D*).

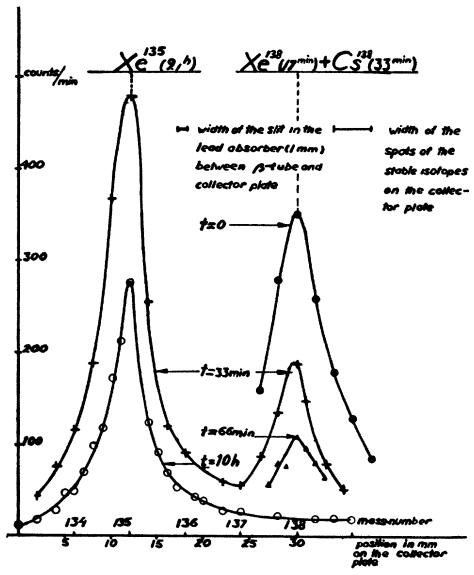

FIG. 1c. The activity of the 17 min. Xe and 33 min. Cs isotopes.

TABLE II. Summary of β-spectrometer investigations.

Isotope	β-max. kev	β-lines	$h\nu$
Xe^{133}	315	25.6 (Auger, medium)	
		30.9 (Auger, weak)	
		46.5 (K 1, very strong)	82.4
		59.3 (K 2? weak)	95.2 (?)
		77.9 (L 1, medium)	83.6
		200 (K 3 weak)	236
Xe^{135}	930	214 (K)	250
		242 (L)	
Xe^{138}	2680		

The activities of Xe^{133}, Xe^{135}, and Cs^{138} on the collector plate, were sufficient for β-spectrometer investigations. The β-spectrometer data are summarized in Table II.

[1] Bergström, Thulin, Svartholm, and Siegbahn, Ark. for Fysik **1**, No. 11 (1949).
[2] I. Bergström and S. Thulin, Phys. Rev. **76**, 313 (1949).
[3] Koch, Kofoed-Hansen, Kristensen, and Drost-Hansen, Phys. Rev. **76**, 279 (1949).

Second Sound and Classical Heat Flow[a,*]

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THE reversibility of the thermomechanical effect in liquid helium II and the inertial characteristics of the associated heat flow result in the true wave characteristics of second sound. In the portion of a second sound cycle where heat flows toward cooler regions, mechanical energy is stored as energy of internal convection. During the opposite half of the cycle heat flows toward warmer regions at the expense of this stored energy. The resulting average mechanical energy content of the wave provides a net mechanical energy flow or *intensity* in the direction of propagation.

Considerations of second sound are simplified by assuming square wave pulses, logical justification lying in the known absence of frequency dispersion. This obviates the distinction between instantaneous and average values. If heat flow density $\dot{H}$ (cal./sec. cm^2) is sustained by liquid helium II during the generation of a one-dimensional square wave heat pulse, the temperature is raised by τ within a heated region which is progressing at the rate of second sound velocity v_2. This requires[1-4] that

$$\dot{H}=\rho c_v \tau v_2, \tag{1}$$

where ρ is the density and c_v the specific heat capacity per gram for helium II. The generation of this second sound actually requires slightly greater heat input than the heating rate $\dot{H}$, to provide the kinetic energy of internal convection stored in the pulse. At the abrupt front of the temperature pulse heat flows continuously out toward the ambient temperature region, cooler by amount τ. According to the second law of thermodynamics** the rate of mechanical energy generation, or intensity γ, is related to temperature by

$$\gamma/\dot{H}=\tau/T_0, \tag{2}$$

where T_0 is the ambient absolute temperature (°K). The intensity becomes[3,5]

$$\gamma=\tau\dot{H}/T_0=\rho c_v v_2 \tau^2/T_0. \tag{3}$$

This expression*** is equally significant with respect to classical heat flow within ordinary materials.

Finally, combining (1) and (2) the expression for total energy flow (thermal plus mechanical) becomes

$$\text{energy flow}=\rho c_v v_2 \tau[1+\tau/T_0] \tag{4}$$

indicating the flow of mechanical energy within a second sound packet to be but the fraction τ/T_0 of the associated heat flow.

Second sound possesses a wave momentum and a radiation pressure. At a chosen position and instant, whichever fluid component happens to be moving in the direction of propagation possesses greater than ambient density, whereas the other component is necessarily retrogressing at less. Accordingly therefore, in the identical manner as for classical sound, the wave momentum flow J for the pulses equals the mechanical energy density divided by wave velocity, equal in turn to radiation pressure P_{rad}.

$$P_{\text{rad}}=J=\rho c_v \tau^2/T_0 \tag{5}$$

or twice (5) for reflection from a thermally non-conducting barrier.**** Although of second-order magnitude, this is the sole existent pressure for second sound! This should not be confused with the small amount of first sound coupled[6] to second sound by the thermal coefficient of expansion of helium II. (It should be noted that the method of deriving the expression automatically includes both kinetic and potential energy density; for continuous waves a factor $\frac{1}{2}$ would appear). Thus under appropriate experimental conditions there would be a "sound current" associated with second sound (as with ordinary sound) of velocity $c_v\tau^2/v_2T_0$.

Thermal boundary conditions early employed by the author (for setting up "thermal impedances") in design of second sound systems were the continuity of temperature and heat flow density between liquid helium II and adjacent classical solids. Thus for second sound normally incident upon a classical barrier

$$\tau_i+\tau_r=\tau_{tr}, \quad \dot{H}_i-\dot{H}_r=\dot{H}_{tr}, \tag{6}$$

where the subscripts (i) and (r) refer, respectively, to incident and reflected second sound, (tr) to transmitted classical thermal waves.

Employing (1) we obtain from (6)

$$\frac{\tau_i\dot{H}_i}{T_0}-\frac{\tau_r\dot{H}_r}{T_0}=\frac{\tau_{tr}\dot{H}_{tr}}{T_0}, \tag{7}$$

where complex conjugates are not used since instantaneous values are desired. Equations (1) and (6) can also be employed to show that for most cases not all of the incident second sound energy is reflected; thermal impedance[4] $\tau/\dot{H}$ equals $[\rho c_v v_2]^{-1}$ for helium II [see (1)] and is entirely real, and may for solid boundaries possess a real component as large as the imaginary component. The essence of (7) is therefore that the temperature wave† entering the solid possesses an *intensity* $\tau\dot{H}/T_0$ in the same manner as does second sound. (This is likewise required for the converse case of second sound waves in helium II being set up by thermal waves emerging from an adjacent solid.) But the well-known *expression for classical thermal waves involves rapid damping, so that the associated energy thereby lost reappears in other forms.*

Certain speculations may be made in this regard. The "kinetic energy" density of the thermal pulse may tentatively be regarded as associated with the mass flow inherent to thermal conduction. Correspondingly "potential energy" density should be related to pressure alterations accompanying thermal flow. The second law of thermodynamics as given by (2) thus holds for thermal conduction across a layer of classical material of thickness less than the thermal wave-length. Analysis based on the thermal impedance concept[4] reveals that second sound pulses should be transmitted without distortion†† or appreciable loss through layers of classical material of such thinness immersed in liquid helium II, thus conforming to conditions of complete reversibility. Arguments similar to those employed by Rayleigh[7] for a classical sound pulse indicate that the mechanical energy flow $\tau\dot{H}/T_0$ involved is shared equally between kinetic and potential forms, not only for second sound but also for classical thermal waves.

When penetration of thermal waves into classical materials exceeds several mean-free-path lengths, the reversibility between heat flow and mechanical energy stated by (2) is necessarily affected by the natural collisions occurring between particles or between phonons. Accordingly the well-known damping sets in and converts the "mechanical energy" content of the thermal wave to acoustical or thermal forms, depending upon the geometry and the substances (thermal coefficient of expansion) involved.