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Argonne National Laboratory

PHYSICS DIVISION

SUMMARY REPORT

January-February, 1961

DISCLAIMER

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Physics
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ARGONNE NATIONAL LABORATORY
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PHYSICS DIVISION SUMMARY REPORT

January-February, 1961

Morton Hamermesh, Division Director

Preceding Summary Reports:

ANL-6214 - September-October 1960
ANL-6235 - November 1960
ANL-6262 - December 1960

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FOREWORD

The Summary Report of the Physics Division of the Argonne National Laboratory is issued monthly for the information of the members of the Division and a limited number of other persons interested in the progress of the work. Each active project reports about once in 3 months, on the average. Those not reported in a particular issue are listed separately in the Table of Contents with a reference to the last issue in which each appeared.

This is merely an informal progress report. The results and data therefore must be understood to be preliminary and tentative.

The issuance of these reports is not intended to constitute publication any any sense of the word. Final results either will be submitted for publication in regular professional journals or, in special cases, will be presented in ANL Topical Reports.

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I. EXPERIMENTAL NUCLEAR PHYSICS

I-30-2 Decay of $_{68}Er^{161}$ (3.1 hr) (51210-01)

H. A. Grench and S. B. Burson

This project has been completed and the results have been published in a report entitled "Decay of $_{68}Er^{161}$ (3.1 hr)," H. A. Grench and S. B. Burson, Phys. Rev. 121, 831-840 (February 1, 1961).

I-80-27 Molecular Beam Studies (51210-01)

William Childs and John Dalman
Reported by William Childs

Goodman and Wexler,[1] in their study of the $P_{1/2}$ atomic ground state of 50-day In^{114m}, obtained the results I = 5 and $\mu_I = +4.7 \pm 0.1$ nm. They pointed out, however, that a systematic error as large as 0.5 nm might be present in their result for the nuclear dipole moment. The purpose of the present experiment, in addition to reducing the uncertainty in μ_I, was to measure the electric quadrupole moment by examining the hyperfine structure of In^{114m} in its metastable atomic $P_{3/2}$ state.

Since only 20% of the In^{114m} atoms in the atomic beam are in the $P_{3/2}$ state, it was anticipated that separation of the $P_{3/2}$ resonances from the background of atoms in both atomic states would be difficult. It was proposed to overcome the low resonance counting rate by taking full advantage

[1] L. S. Goodman and S. Wexler, Phys. Rev. 108, 1524 (1957).

of the great reduction in the background of the counting equipment as compared with the previous experiment.

Because of a long delay in shipment from MTR, the source was found to be considerably weaker than anticipated. Nevertheless, it was still possible to obtain useful data if sufficiently long counting times were employed. The signal-to-noise ratio found (2 : 1) has made it possible to work with resonances only one count per minute above background. This represents about 5 times the sensitivity of our previous work.

The results obtained to date are:

$$I = 5$$

$$a(P_{3/2}) = +193.8 \pm 2.8 \text{ Mc/sec}$$

$$b(P_{3/2}) = +313 \pm 34 \text{ Mc/sec}$$

$$\mu_I = +4.92 \pm 0.07 \text{ nm}$$

$$Q = +0.58 \pm 0.06 \text{ b.}$$

A second In^{114m} sample, of specific activity at least equal to that of the first, is being prepared to check and further refine the preliminary results given above.

Several students temporarily associated with the project have made a worthwhile addition to our rf equipment. The unit contains two parts: a 20-50 Mc/sec tuned amplifier, and a 55-100 Mc/sec frequency-doubler amplifier. The new amplifier, together with the 0.5-25 Mc/sec amplifier built several years ago, now provides high-level rf power (into 50 ohms) almost to 100 Mc/sec.

Progress on assembling the new atomic-beam machine has not been as rapid as had been hoped. Although a good deal of the hardware has been assembled, several critical parts still have not been delivered. All parts are, however, promised for early in 1961.

Initial tests of the ionizer-detector, designed by Berkowitz and Dalman for the new machine, establish that ions are indeed produced and detected in a vacuum below 10^{-6} mm Hg. The attempt to study focussing properties and efficiency by accelerating the ions into a scintillator failed

because of the low intensity. It is planned instead to optimize the optics by studying individual mass groups resolved in the spectrometer magnet.

Abstracts were presented on 2.6-hr Mn^{56} and 12-day Ge^{71} at the Brookhaven Conference on Molecular Beams on November 3-5, 1960. The latter abstract was also presented at the Chicago meeting of the American Physical Society on November 25, 1960.

Papers on the hfs of Ho^{166} and Mn^{56} have been submitted for publication in the Physical Review.

I-144-12 Investigations of Scintillators (51300-01)

L. J. Basile

Lifetime measurements have been carried out for the emission of light by polystyrenes of various molecular weights. The molecular weight of the polystyrene was varied by changing the temperature of polymerization. The length of time the samples were kept in the oil bath depended on the temperature. Samples polymerized at 85°C were held at temperature for 18 days; at 110°C, 125°C, and 145°C for a period of 10 days; at 170°C for a period of 150 hr. Generally speaking, the lower the temperature of polymerization, the higher the average molecular weight. Polystyrene of high molecular weight was obtained by adding varying amounts of crosslinking agent to the styrene monomer before polymerization. The crosslinking agent was high-purity divinylbenzene, about 85% pure. The samples containing crosslinking agent were polymerized at 145°C for 10 days.

The data for the lifetimes of the various polystyrene samples are given in Table I. The difference between the thick and thin samples shows the effect that self-absorption has on the measured lifetime. It should be noted that these values are obtained by determining the slope of the best linear

TABLE I. Decay times of various polystyrene samples. Thick samples measured 12 mm thick by 2 cm in diameter; thin samples were 1/2 mm thick by 5 mm in diameter. For the crosslinked polystyrene the values in the parentheses are for the concentration of the crosslinking agent divinylbenzene.

Polymerization temperature					
85°	110°	125°	145°	170°	Cross-linked
			Thick Samples		
8.7	13.3	14.7	14.1	13.3	14.9 (10 λ)
8.4	13.1	14.4	14.2	13.5	15.0 (25 λ)
8.9	13.0	14.4	14.0	13.8	15.0 (50 λ)
8.6	13.0	14.7	14.8	13.8	14.8 (125 λ)
	13.2				15.1 (175 λ)
	13.2				
			Thin Samples		
7.2	12.6	13.5	13.7	13.3	
7.6	12.8	14.0	13.5	13.2	
8.0	12.7	13.7	13.5	13.3	
8.2	12.8	14.0	13.2		

fit to a semilogarithmic plot of the decaying part of the pulse. The time for the intensity of the pulse to decrease by a factor of e is taken as the characteristic decay time. This assumes that the intensity I can be described by a simple exponential $I = A e^{-t/\tau}$. Numerous experiments on the lifetime of pure polystyrene have shown that the light pulse does obey a simple exponential law for at least two-thirds of the decaying part of the pulse. In the tailing part of the pulse there are many fluctuations which are believed to be mainly of instrumental origin.

Recently Kilin and Rozman have published data on the lifetime of the fluorescence in polystyrene.[1] Their data, obtained with a phase fluorometer in conjunction with a modulated electron beam, show that the fluorescence decay of polystyrene does not obey a simple exponential decay law. However, it is practically impossible to obtain the true shape of the pulse by using a phase fluorometer since it only measures the difference in the phase angle between the modulation of the exciting light and that of the emitting light. Thus the over-all pulse may well be nonexponential. In addition, the values that Kilin and Rozman report are 15-25% lower than our values.

One possible explanation of this discrepancy is that the samples used by these authors were not fully polymerized. That is, there may be some residual monomer present which acts as a quencher and therefore reduces the observed decay time. To test this possibility, absorption spectra were measured for some representative samples of polystyrene. We observed a characteristic absorption peak at 2910A which we attribute to trace amounts of styrene monomer. For the samples that we measured, calculations showed that the residual monomer concentration was less than 0.1%. It should also be pointed out that the samples of polystyrene that were polymerized at 85°C began to craze after standing in air for two weeks. This indicates that the residual monomer concentration, or volatile components, were greater than 1.5% since work elsewhere indicates that polystyrene can have this amount of volatile components before crazing.[2]

How the residual styrene monomer affects the lifetime of polystyrene is not too certain at present. If it acts as a quencher, it certainly is an effective one. This may partly explain the discrepancy between our results and those reported by Kilin and Rozman.

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[1] S. F. Kilin and I. M. Rozman, Optics and Spectroscopy 4, 37 (1959).

[2] R. H. Boundy and R. F. Boyer, Styrene: Its Polymers, Copolymers, and Derivatives (Reinhold Publishing Corporation, New York, 1952), Chap. 11, p. 536.

II. MASS SPECTROSCOPY

II-30-1 Scintillation Ion Detector (51300-01)

Sol Wexler

Researchers using mass spectrometric techniques in the United States have invariably employed electron multipliers installed inside the vacuum system when high sensitivities were desired. Although these multipliers are extremely sensitive, being able to detect individual ions, they suffer from several disadvantages. They are difficult to construct, and the proper activation of the dynode surface necessary for high gain is still an art. Secondly, their gain often decreases with time, especially on exposure to air or other gases. Finally, they are particularly sensitive to radioactive gases, which often cause contamination of the dynode surfaces and consequently high noise backgrounds.

Contrary to practice in this country, workers in England[1] and Germany[2,3] have been developing ion detectors that make use of the secondary electrons emitted from surfaces struck by ions. The electrons are accelerated to a scintillating material in which they produce light flashes which are in turn detected by a photomultiplier outside the vacuum system of the spectrometer. Advantages of this system are the simplicity of construction and the easy replacement of the commercial photomultiplier tube. This report describes the construction and performance of a scintillation ion detector which is a modification of a design of Daly.[1]

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1 N. R. Daly, Rev. Sci. Instr. 31, 264 (1960).

2 W. Schütze and F. Bernhard, Z. Physik 145, 44 (1956).

3 E. Schoenheit, Z. Naturforsch. 15A, 839 (1960).

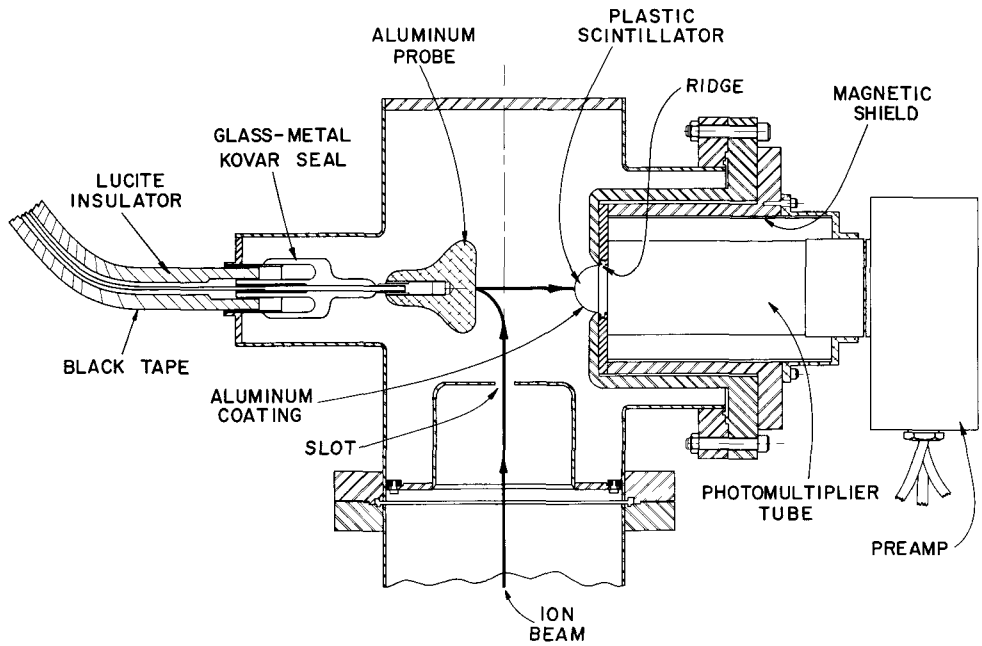

Fig. 1. Scintillation ion detector constructed for use in the mass spectrometer for radioactive gases.

The detector, constructed for use in the mass spectrometer for radioactive gases, appears in Fig. 1. The 6-kev ion beam, after passing through the detector slit of the spectrometer, enters the detector chamber through a large slot (1 in. X 1/2 in.) which serves to isolate the electric field in the chamber and acts as a pumping port for the compartment. The positive ions of the beam are drawn to an aluminum probe held at a negative potential of 35-40 kv. Each ion striking the surface of the probe causes the release of several secondary electrons, which are accelerated toward a hemispherical scintillating plastic (Pilot B). The latter is covered by a thin coat of aluminum (about 0.03 μ thick) which serves to ground the scintillator electrically and to reflect light toward a commercial photomultiplier on the external side of the plastic. Good optical contact between plastic and photomultiplier is made with a thin film of Dow silicone grease (No. QC-20057). The multiplier is shielded from stray magnetic fields by Mu-Metal. A very high polish is placed

on all internal surfaces (particularly on the probe surface) to avoid electrical breakdowns of the very high voltage on the probe. A circular ridge 0.015 in. high, which is pressed into the plastic by a flange bolted onto the system, is an effective vacuum seal for the scintillator.

The electron multiplier is operated with the photocathode grounded and the anode at high positive potential. The signal pulses are brought through a 0.001 μf coupling condenser to a cathode follower and then to an amplifier. The amplified pulses are fed to a single-channel analyzer with discriminator, the output of which is both counted directly by a scaling circuit and transformed by a counting-rate meter for presentation on a moving-chart recorder.

Several variables, such as position and voltage of probe, make of photomultiplier tube, internal gain of multiplier, and external amplification, were systematically varied to arrive at the best signal-to-noise ratio. The following operating conditions were selected: probe voltage, 35 kv negative; make of photomultiplier, EMI-9558 (EMI Electronics Ltd., Ruislip, Middlesex, England); voltage on multiplier, 1080 v (98 v/stage); gain of amplifier, 1500; discriminator level, 4 v. With these conditions and a prior cleaning of the probe by means of a discharge through a N_2 atmosphere at about 1 mm pressure for 2-3 min (the probe was held at -1200 v), the background was found to be 1.2 cps while 99% of the ions of each mass which hit the probe were detected. In Fig. 2, the variation of the number of detected ions of a given mass is plotted as a function of the negative voltage of the probe. The signal is seen to be saturated at 35 kv. A typical pulse-height distribution of the mass peak of an organic gaseous ion appears in Fig. 3. Data such as those plotted in the two figures demonstrate that virtually every ion which enters the detector is observed.

The detector has been found to be very suitable for measuring very low intensities of ions produced by electron impact on inactive gases and by beta decay of radioactive gases. However, it is extremely sensitive

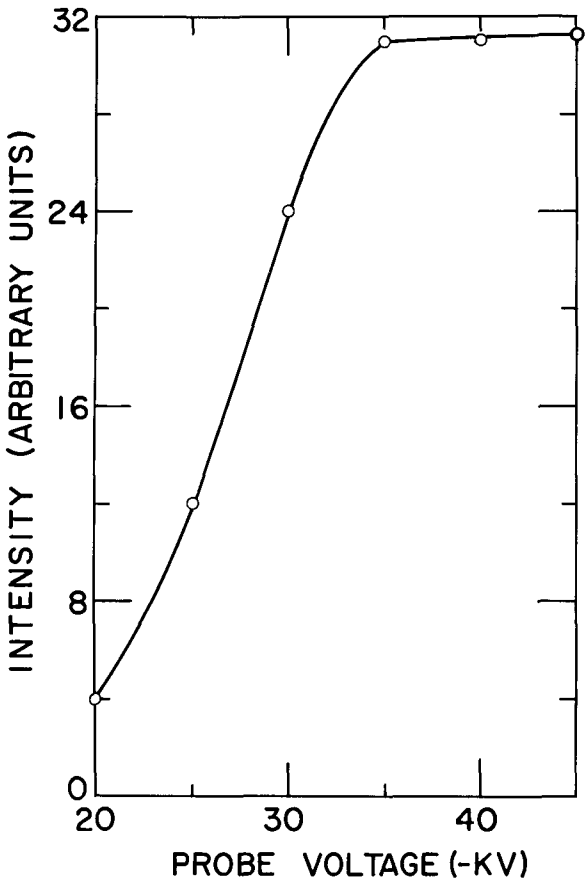

Fig. 2. Variation of ion intensity with negative voltage on the probe from which secondary electrons are produced.

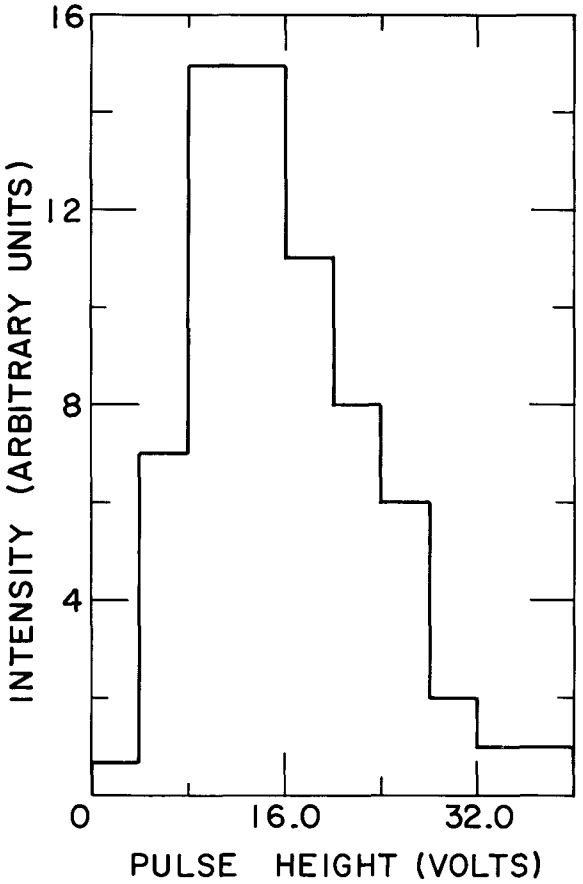

Fig. 3. A typical pulse-height distribution of the signal of an organic ion.

to x and γ rays, much more so than internal electron multipliers. Extensive shielding is required to keep the background noise from these sources at manageable levels.

III. CRYSTALLOGRAPHY

III-7-1 The Crystal Structure of Gadolinium Trichloride Hexahydrate (51300-01)

Massimo Marezio,* H. A. Plettinger, and W. H. Zachariasen
Reported by H. A. Plettinger

The compound $GdCl_3 \cdot 6H_2O$ is representative of an isostructure series with numerous members. It is definitely known that the corresponding compounds of neodymium, samarium, erbium, and plutonium have the same structure as $GdCl_3 \cdot 6H_2O$, and it is probably true that most of the analogous chlorides and bromides of 4f and 5f elements, of yttrium, and possibly of scandium belong to the same structure type.

Because of the ease with which large (although hygroscopic) single crystals can be prepared, extensive magnetic and spectroscopic measurements have been made on many of these compounds. It is hoped that the structure results will be useful in the interpretation of these data.

The single crystals used in the present investigation were furnished by Professor G. H. Dieke of Johns Hopkins University.

$GdCl_3 \cdot 6H_2O$ is monoclinic with two molecules in a unit cell of dimensions $a = 9.651 \pm 0.001$ A, $b = 6.525 \pm 0.001$ A, $c = 7.923 \pm 0.001$ A, $\beta = 93.65 \pm 0.02^{\circ}$. The calculated density is 2.478 g cm^{-3}.

All intensity measurements were made on a General Electric XRD-3 spectrometer rebuilt for single-crystal work. A proportional counter and filtered Cu Kα radiation were used. All data were taken on one crystal which had been ground into a sphere of radius $2.83 \pm 0.02 \times 10^{-2}$ cm. Since the crystals are hygroscopic, the sphere was coated with a solution of Canada balsam in benzene.

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*University of Chicago; on leave from Istituto di Chimica Generale e Inorganica dell' Universita di Roma.

The final values of the parameters (for all but the hydrogen atoms) given in Table II were obtained by least-squares refinement by use of the Busing-Levi program[1] for IBM-704, and all 794 experimental structure factors.

TABLE II. Final parameters.

Atom	Position	x	y	z	B in A^2
Gd	2e	1/4	0.1521 ± 2	1/4	0.72 ± 3
Cl_I	2f	3/4	0.3769 ± 4	1/4	3.06 ± 11
Cl_{II}	4g	0.0587 ± 4	0.8370 ± 8	0.2601 ± 4	2.92 ± 8
O_I	4g	0.2813 ± 12	0.0471 ± 19	0.5432 ± 12	2.94 ± 21
O_{II}	4g	0.1423 ± 12	0.4254 ± 20	0.0888 ± 12	3.24 ± 22
O_{III}	4g	0.4406 ± 12	0.2988 ± 20	0.1058 ± 12	3.26 ± 22

DISCUSSION OF THE RESULTS

It is an unexpected feature of the structure that one third of the chlorine atoms (the Cl_I atoms) form no bonds with gadolinium atoms. Indeed, the shortest Gd—Cl_I distance is greater than 5 A.

In the structure there are complexes $[Cl_2Gd(OH_2)_6]$, each C_{II} atom and each oxygen atom being bonded to one gadolinium atom. These complexes are held together by O — H $\cdots$ Cl_I and O — H $\cdots$ Cl_{II} bonds.

The bond lengths within the complex are:

[1] W. R. Busing and H. A. Levi, Oak Ridge National Laboratory Report 59-4-37 (1959).

$Gd - 2\,Cl_{II}$	2.768 ± 0.008 A
$Gd - 2\,O_{I}$	2.42 ± 0.02 A
$Gd - 2\,O_{II}$	2.39 ± 0.02 A
$Gd - 2\,O_{III}$	2.42 ± 0.02 A

The closest oxygen and chlorine approaches in the complex are $O_I - O_{II} = 2.80$ A, $Cl_{II} - O_{III} = 3.20$ A, and $Cl_{II} - Cl_{II} = 3.71$ A.

Each oxygen atom has a Cl_I atom at a distance of 3.17 – 3.24 A and a C_{II} atom of an adjacent complex at 3.14 - 3.18 A. These short distances suggest the presence of bonds $O - H \cdots Cl$, and this interpretation is given further support by the fact that the angle between the two $O - H \cdots Cl$ bonds is 89-97°.

Conversely each Cl_I atom forms six $Cl_I \cdots H - O$ bonds and each Cl_{II} atom three $Cl_{II} \cdots H - O$ bonds in addition to the Cl_{II}–Gd bond.

V. THEORETICAL PHYSICS, GENERAL

V-5-1 Geometric Properties of Angular Distributions of Decay Products (51210-01)

Murray Peshkin

Unstable systems formed in a reaction are necessarily aligned if the number of pure quantum states in which they are prepared is smaller than their spin s. Then the statistical matrix which describes the ensemble of unstable particles contains anisotropic terms, which result in anisotropic angular distributions of the decay products. We give inequalities which may be used to bound s from above. Our results constitute an improvement, as well as a generalization, of the method of Eberhard and Good. This development has been described in a paper entitled "Asymmetry Theorems for Decay Products", which has been written for publication.

The possibility of useful generalization of the method of Lee and Yang in the parity-mixing case is being investigated.

V-15-11 Statistical Properties of Nuclear Energy States (51210-01)

Norbert Rosenzweig

DISPERSION OF GYROMAGNETIC RATIOS IN COMPLEX SPECTRA

Some consequences of a statistical hypothesis for the Hamiltonian

proposed by Wigner[1] for highly excited nuclear states were reported previously. In particular, a varying degree of repulsion of atomic energy levels was explained in terms of a suitable random matrix hypothesis which takes into account the relative strengths of spin-orbit and Coulomb interactions.[2,3] The random-matrix hypothesis also implies that the associated eigenfunctions have statistical properties which are similar to those of a random vector that is uniformly distributed on the surface of a unit sphere of very high dimensionality. This property of the wave function was used in reference 2 for a derivation of the distribution of neutron widths.[4] It is now found that the same ideas lead to some interesting statistical properties for the gyromagnetic ratios of complex quantum systems, and that these properties are easily discerned in the abundant experimental material of atomic spectroscopy.[5]

As an illustration, let us consider the hypothetical case of a complex atom in which a limited number of electron configurations interact strongly with one another but only very weakly (or not at all) with all other configurations. Suppose N energy levels of one particular parity and J value arise in these configurations. It is further assumed that these N states interact strongly in the SL coupling scheme (i.e., we want to consider the case of intermediate coupling). Let ϕ_j ($j = 1, \cdots, N$) denote a complete orthonormal set of SLJ wave functions and g_j the well known Landé factor. Let ψ_i ($i = 1, \cdots, N$) denote the correct wavefunction and G_i the associated gyromagnetic ratio. We have the well known relations

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[1] E. P. Wigner, Gatlinburg Conference on Neutron Physics by Time-of-Flight, Oak Ridge National Laboratory Report-2309, 1957 (unpublished) p. 59.

[2] C. E. Porter and N. Rosenzweig, Ann. Acad. Scient. Fennicae, No. 44 (1960).

[3] N. Rosenzweig and C. E. Porter, Phys. Rev. 120, 1698 (1960).

[4] First obtained by R. G. Thomas and C. E. Porter, Phys. Rev. 104, 483 (1956).

[5] C. E. Moore, Atomic Energy Levels, National Bureau of Standards Circular 467.

$$\psi_i = \sum_j U_{ij} \phi_j , \quad UU^T = 1 \tag{1}$$

and the g sum rule

$$\langle G \rangle = \langle g \rangle , \tag{2}$$

where the average is to be performed, of course, over the N states in question. The dispersion of the correct gyromagnetic ratios about the mean $\langle G \rangle$ is given by

$$\langle G^2 \rangle - \langle G \rangle^2 = \sum_{j,k} g_j g_k \sum_i \frac{1}{N} U_{ij}^2 U_{ik}^2 - \langle g \rangle^2 . \tag{3}$$

Strictly speaking, the sum $\sum_i U_{ij}^2 U_{ik}^2$ depends on the particular matrix U. However, if the system is sufficiently complex then one may expect that this dependence will be rather weak. In the spirit of the earlier work, let us introduce the hypothesis that the sum will be given approximately by its average value over the invariant distribution of orthogonal matrices in N dimensions.[6] This leads to the result

$$h^2 \equiv \frac{\langle G^2 \rangle - \langle G \rangle^2}{\langle g^2 \rangle - \langle g \rangle^2} = \frac{2}{N+2} , \tag{4}$$

which shows that the dispersion of the true gyromagnetic ratios may be expected to be much smaller than the dispersion of the Landé g factors in the LS coupling limit. This result (suitably modified to take into account the presence of both neutrons and protons and their intrinsic magnetic moments) suggests to us that the nuclear levels of a given parity and spin at sufficiently high excitation will have nearly the same magnetic moment.

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[6] As in our previous work, we neglect for simplicity the selection rules for spin-orbit coupling.

For example, this prediction applies to the resonance levels observed in the reaction $n + U^{238}$.

The extreme statistical model leading to Eq. (4) can not be expected to apply to atomic spectra without some modification because it is found[7] that even in intermediate coupling one particular LS component frequently dominates the wave function. However, a statistical treatment is still possible without serious inconsistencies. In analogy with (1) we now write

$$\psi_i = a_i \phi_i + b_i \sum_j U_{ij} \phi_j \quad , \quad UU^T = 1, \tag{5}$$

where ϕ_i is the dominant LS component. Applying the same statistical hypothesis to U, one now obtains

$$\hbar^2 = \left\langle (1 - b^2)^2 \right\rangle + \left\langle b^4 \right\rangle \frac{2}{N+2} \quad . \tag{6}$$

Pure LS coupling corresponds to $b \to 0$, in which case $\hbar^2 \to 1$. In the opposite limit $b \to 1$ and $\hbar^2$ is reduced to the small value given by Eq. (4). Thus one expects to find a systematic decrease in the value of $\hbar^2$ as the departure from LS coupling increases.

To a fairly good approximation, the spectra which are homologous with those of the iron group of elements may be regarded as arising from the same electron configurations. Thus, according to the above theory, the differences in the dispersion of the true G values should be determined entirely by the degree of departure from LS coupling. Generally speaking, this departure increases with increasing atomic number. Corres-

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[7] For example, R. E. Trees, Phys. Rev. 49, 838 (1959).

pondingly, $\hbar^2$ should decrease with increasing atomic number, and this is indeed found to be the case. As illustration, some results for the odd-parity levels of Fe I, Ru I and Os I are shown in Table III, in which n_J denotes the number of

TABLE III. Average values and dispersions of measured G factors compared with the corresponding quantities g in the LS coupling limits for the three homologous elements Fe, Ru, and Os.

Spectrum	J	n_j	$\langle G \rangle$	$\langle g \rangle$	$\langle G^2 \rangle - \langle G \rangle^2$	$\langle g^2 \rangle - \langle g \rangle^2$	$\hbar^2$
Fe I	1	35	1.33	1.33	0.648	0.755	0.856
	2	50	1.25	1.26	0.242	0.263	0.919
	3	53	1.21	1.21	0.109	0.116	0.939
	4	47	1.19	1.20	0.061	0.066	0.920
	5	35	1.17	1.18	0.033	0.035	0.934
	6	16	1.19	1.19	0.018	0.019	0.953
Ru I	1	21	1.18	1.17	0.301	0.532	0.566
	2	32	1.28	1.28	0.191	0.232	0.823
	3	27	1.26	1.26	0.070	0.092	0.761
	4	20	1.26	1.27	0.051	0.069	0.734
	5	17	1.20	1.20	0.035	0.040	0.860
	6	6	1.23	1.25	0.022	0.024	0.928
Os I	1	25	1.21	a	0.181	a	0.6[b]
	2	36	1.28	a	0.094	a	0.5[b]
	3	38	1.26	a	0.037	a	0.5[b]
	4	32	1.24	a	0.025	a	0.5[b]
	5	13	1.28	a	0.014	a	0.4[b]
	6	10	1.22	a	0.011	a	0.5[b]

[a] The number of levels for which LS assignments have been made are not sufficient to permit a direct estimate.

[b] Estimated by using the values of $\langle g^2 \rangle - \langle g \rangle^2$ of Ru I.

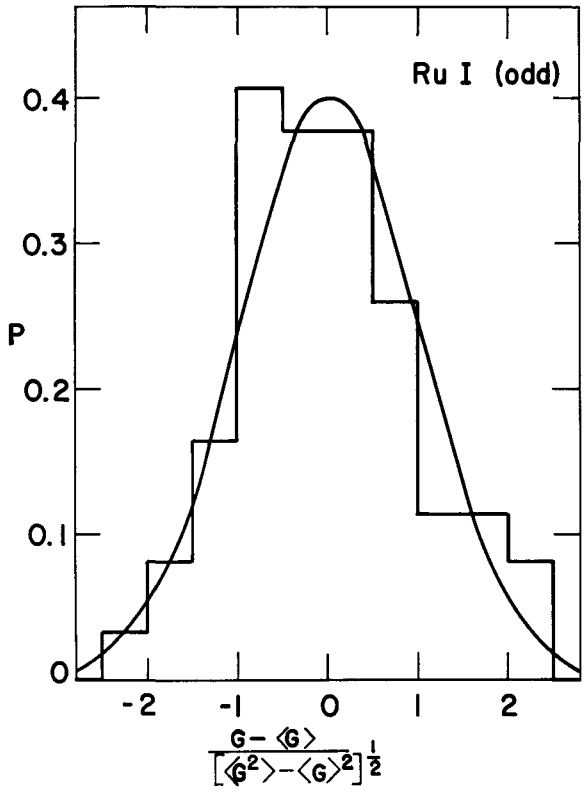

Fig. 4. Distribution of experimentally observed G values for the odd-parity levels of Ru I.

levels with a given J value in the computation of the averages. In the case of Fe I and Ru I, only those levels were considered for which G has been measured and S L values have been assigned. However, in the case of Os I the number of levels for which definite values of S and L have been assigned is so small that we have used all the levels for which G has been determined. The following points should be noted. 1) Although the states for which G has been measured do not form a complete set, the data are sufficiently representative for the sum rule (2) to hold in a statistical sense. In this connection, the comparison for Ru I, in which there is an appreciable departure from LS coupling, is more significant than the case of Fe I. 2) For a fixed value of J the dispersion $\langle G^2 \rangle - \langle G \rangle^2$, and also the ratio $\hbar^2$ decreases with increasing atomic number. 3) For a fixed element, $\langle G^2 \rangle - \langle G \rangle^2$ decreases with increasing value of J. This can be understood in terms of the dependence of the Landé g factor on S, L, and J and the proportionality of the two dispersions which is exhibited by both (4) and (6).

We have also studied the empirical distribution of G for many elements and find it to be fairly close to Gaussian. The situation is illustrated in Fig. 4 for the 123 odd levels of Ru I. (The plot is actually a superposition of six histograms, one for each value of J.)

Further effort is being devoted to 1) the formal derivation

of the distribution of G for a given distribution of g; 2) an investigation of the distribution of g on the basis of realistic distributions of the energy levels with regard to S, L, and J; and 3) a detailed comparison of the above statistical theory with results obtained in the theory of complex spectra in order to indicate the extent to which formula (6) has quantitative validity.

A similar statistical treatment has been proposed independently by C. E. Porter.

V-18-5 Elementary Particles in de Sitter Space (51151-01)

William C. Davidon

Symmetry assumptions are not determined a priori, but are an extrapolation from a wide variety of experience. Geometrical and kinematical relationships among space-time events provide direct tests of these assumptions, and it is therefore essential that the connection between symmetry and these relationships be made as directly and realistically as possible.

It has been customary to take the magnitude of the invariant interval between two space-time events as the fundamental quantity corresponding to a physical measurement. For macroscopic systems, the determination of this interval by means of clocks and meter sticks is unambiguous. However, both on a microscopic and a cosmic scale, no corresponding elementary procedures exist.

On a microscopic scale, two types of difficulties arise. One is associated with quantum phenomena, and necessitates going to increasing energies in order to determine space-time relations in regions of diminishing size. However, were point particles of arbitrary energy available,

there would be, in principle, no limit to the fineness of detail with which we could investigate space-time structures, and only the technological problems associated with building high-energy accelerators would retard these investigations.

In addition to these quantum limitations, however, which do not determine any fundamental length, there is the limitation imposed by the characteristic dimensions of elementary particles. Though cosmic rays, and presumably eventually accelerators, are sources of quanta whose wavelengths may be much smaller than 10^{-13} cm, the mass and charge distributions of elementary particles probably cannot be altered.

On a cosmic scale, limitations of an altogether different kind appear which make the physical measurement of the invariant space-time interval increasingly ambiguous. One which is of technological importance is the difficulty in obtaining an unambiguous correlation between distance and brightness of different types of stars and galaxies. The more fundamental limitation is the fact that cosmic structures probably do not satisfy the postulates of Euclidean geometry, so that the interpretation of intervals of 10^{27} cm becomes far removed from direct observation.

Since symmetry assumptions are of fundamental importance in all physical phenomena, including those of microscopic and cosmic extent, it is of value to provide a geometrical interpretation of these assumptions which is applicable throughout this entire spectrum of events. (It may also be pointed out that, even on a macroscopic scale, the precise determination of one space-time interval would require an infinite amount of information, corresponding to the successive bits of a binary expansion of the numerical value of the interval.)

It has been found possible to use the qualitative concept of temporal ordering in place of the quantitative interval measurement as the fundamental basis of geometrical and kinematical relationships, and hence of symmetry assumptions. That is, we assume there is an unambiguous

operationally defined procedure capable of determining of any two events, A and B, whether or not A precedes B. Though there certainly remain some difficulties in carrying out this procedure, such as in cascade decays of nuclear systems or in comparing two remote cosmic events, these difficulties are not as severe as those of the corresponding quantitative measurements of intervals.

The set of events, temporally ordered, form a structure which mathematically constitutes a partly ordered set. Such a set may be defined by the axioms:

1. No event precedes itself.
2. If A precedes B and B precedes C, then A precedes C.

The order-preserving mappings of the set of events (i.e., the mappings for which if A precedes B, then A' precedes B', where A' and B' are the corresponding images) form a semigroup. Those mappings that both preserve order and have an inverse constitute a group, and this group determines to a large extent the nature of geometrical and kinematical relationships.

The group of all such mappings of events that preserve temporal ordering in the usual space-time contains the usual inhomogeneous Lorentz (or Poincaré) group as a subgroup, but is the conformal group. The additional mappings correspond to (1) changes in scale, spreading or contracting the set of all events, and (2) nonlinear mappings, which do not map straight lines into straight lines, but in general map straight lines into conic sections.

However, if the space-time has any curvature, however small, the group of transformations that preserve order is identical with the group that preserves intervals. Hence in this case, the temporal-order relation alone suffices to fully determine the symmetry group. The symmetry group is then the de Sitter group, which approximates the inhomogeneous Lorentz group locally, but differs from it appreciably for sufficiently large

space-time displacements.

Under inversions, the group properties are qualitatively different. Roughly speaking, one inversion operation is replaced by an immense space-like translation. Physically, only time-like translations of any actual system can be carried out, since to make a given displacement requires at least a time equal to the distance divided by the velocity of light. Nevertheless, the inclusion of this operation in the continuous part of the symmetry group restricts the possible representations of the group. These representations correspond to elementary particles. For a spin-$\frac{1}{2}$ particle with nonzero mass, there is only one possible representation, corresponding to a system with four orthogonal ground states (corresponding to the two spin orientations of both particle and antiparticle). Though a corresponding representation certainly exists for the Lorentz group, other spin-$\frac{1}{2}$ representations exist as well, and additional postulates are required to select this physical one.

V-49-1 Completeness of Quantum Mechanics and Theta-Antitheta Correlations (51151-01)

D. R. Inglis

The question concerning the completeness of quantum mechanics raised long ago by Einstein, Podolsky, and Rosen reduces in the two-spin model of Bohm to the question whether two components of the spin of one particle can have a simultaneous physical reality because either one may be measured through its correlations with the other particle, solely by observation of the latter. The question arises only if one goes beyond

experiment (so far as we know it) as a criterion of physical reality and proposes to assume a separate predetermination for the two particles when the wave function gives only a predetermined correlation. The problem is presented in terms of a graphic description of the two-spin model developed in such a way as to provide a close analogy with the charge-conjugation correlation of two theta particles produced from proton-antiproton annihilation, as proposed by Lee and Yang.

This has been reported in more detail in a paper[1] of which the above is the abstract. This terminates the project.

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[1] D. R. Inglis, Revs. Modern Phys. 33, 1-7 (January 1961).

VI. MISCELLANEOUS

VI-1-1 Weather Modification (51300-01)

D. C. Hess and M. B. Rodin (RE)
Reported by D. C. Hess

A system is proposed whereby clouds are prevented from dropping their moisture content on the windward side of a mountain range by artifically adding sufficient heat so that they may rise enough to clear the mountains without cooling to a temperature which would cause precipitation. Two of the possible ways of delivering heat to the cloud are transmission as electromagnetic radiation, principally in the near infrared region, and direct contact by use of airborne heaters. The infrared transmission system is handicapped by a large amount of absorption in the atmosphere (Fig. 5), large size, and the necessity of developing high temperatures over large areas to handle the power needed. It may prove feasible for special applications. A suggested reflector system is shown in Fig. 6 and its use in Fig. 7. A calculation is made below for heating by direct contact.

A number of assumptions are made about cloud properties, many of which need further experimental justification. The general assumption is that a cloud can be "eased" up by gentle heating or caused to precipitate by rapid heating. As an example, consider the use of the direct contact method to furnish 1 cm of water a day for as many days as desired (not necessarily consecutive) to an area of 100 km^2 (a little more than a township). It is assumed that clouds are at 2 km altitude, need to be raised to 2.7 km to clear the barrier without precipitation, and that there is 3 cc of water (recoverable as rain or snow) per cubic meter of cloud. It is also assumed that maintenance of the cloud at ambient temperature is sufficient to prevent precipitation until desired and that

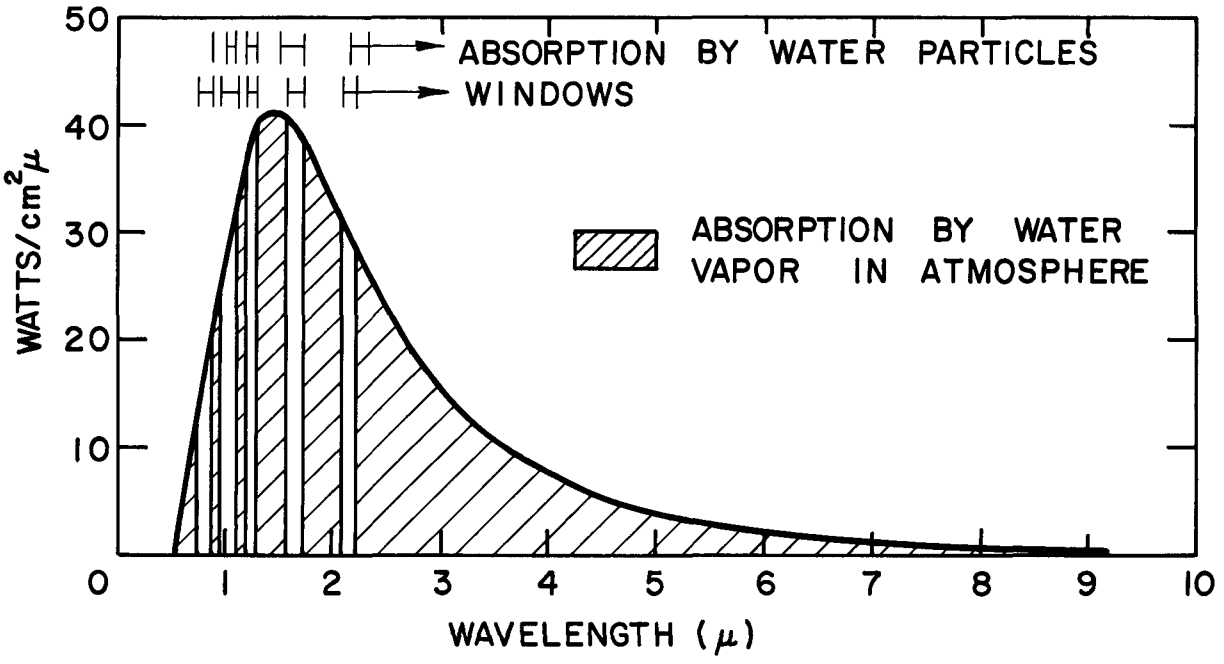

Fig. 5. The energy spectrum emitted from a source at 2000°K is shown by the curve. The energy at wavelengths not absorbed by water vapor is shown in the vertical bands under the curve and constitutes about 20% of the total. The comparison of wavelength bands that can pass through water vapor and wavelength bands that are absorbed by water particles are shown above the curve. The absorption bands shown for the water particles do not include the contribution resulting from Mie scattering. [Adapted from P. Moon, J. Franklin Inst. 230, 583 (1960).] Straight line approximations have been made to the curves given by Moon. The 20-km path corresponds roughly to m = 2.5, i.e., $2\frac{1}{2}$ times the vertical path through the whole atmosphere.

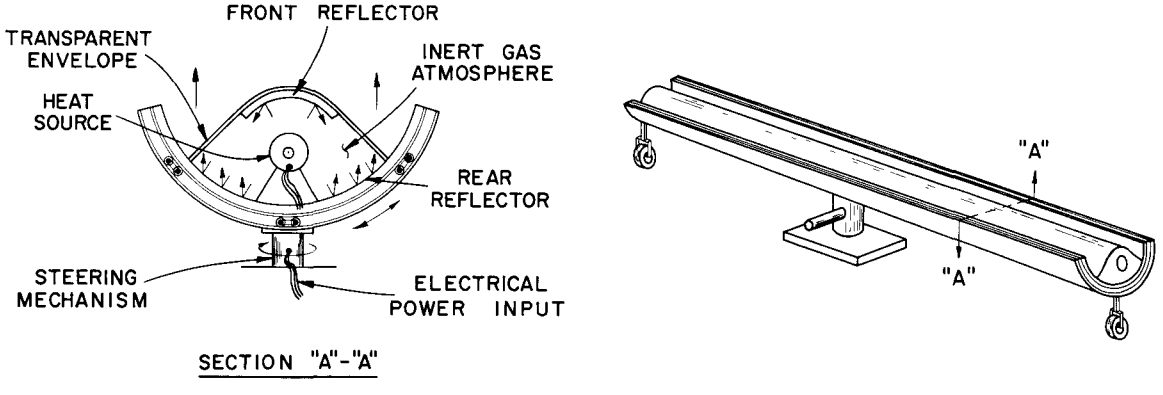

Fig. 6. Section AA', shown on the left of the figure, illustrates some construction features that would be included in the design of the infrared reflector system. The assembled reflector system, including the maneuverable features, are shown on the right.

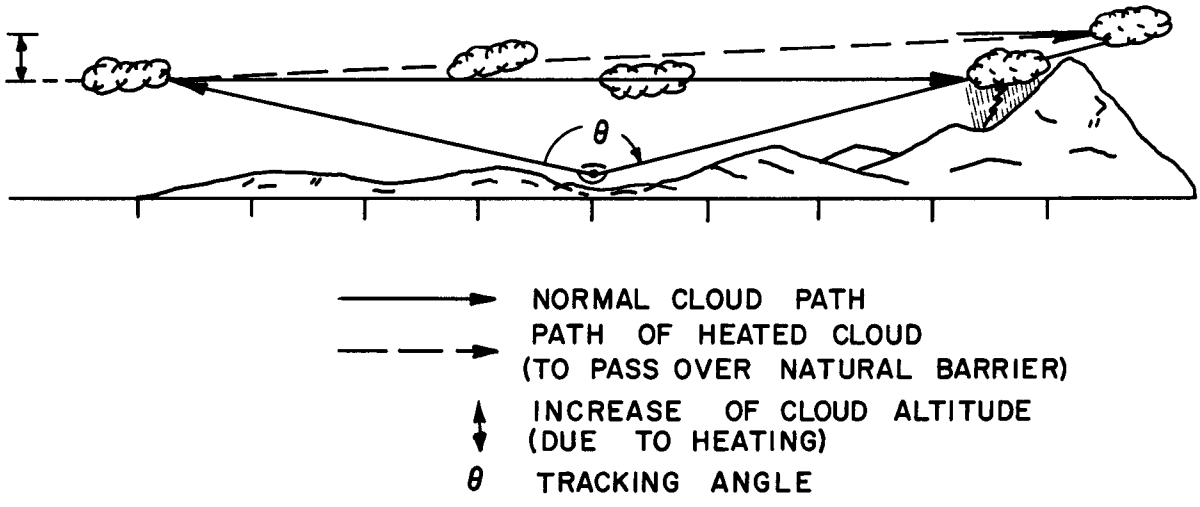

Fig. 7. Schematic drawing showing the installation of the infrared reflector system. It also shows the effect of radiant heating on the course of one cloud, which permits it to pass over the obstruction, and the course followed by an untreated cloud and its subsequent dissipation.

rapid addition of the same amount of heat as was required to lift the cloud is adequate to cause precipitation. Other techniques for causing precipitation, such as cloud seeding, may be preferable. Calculations are summarized in Table IV.

Since a 2000-Mw reactor is about as large as one would want to consider now, the problem would require two reactors for raising and two more for precipitation. The estimates in Table V have been made although no such reactor or other heat source of such magnitude has been airborne.

A sketch indicating the essentials of an airborne nuclear heating system is shown in Fig. 8 and "before" and "after" views of the

TABLE IV. Summary of calculation of amount of heat required to postpone precipitation in clouds capable of furnishing one cm of water to an area of about 40 square miles.

Area to be covered	100 km^2
Water needed for 1 cm precipitation	10^{12} cc
Water available per cubic meter of cloud	3 cc
Volume of clouds needed	3.3×10^{11} m^3
Prevailing lapse rate	0.5° C/100 m
Saturated adiabatic lapse rate in cloud	0.6°C/100 m
Air and cloud temperature at 2 km	3° C
Air temperature at 2.7 km	-0.5° C
Temperature of cloud at 2.7 km without added heat	-1.2° C
To remain at ambient, cloud must be warmed	0.7° C
Average density of clouds between 2.0 and 2.7 km	1.1 kg/m^3
Mass of clouds	3.7×10^{11} kg
Specific heat	250 cal/° C kg
Heat required to warm clouds 0.7° C	6.4×10^{13} cal
	2.7×10^{14} joule
	7.5×10^{7} kw-hr
Power required, 24-hour period	3×10^{3} Mw

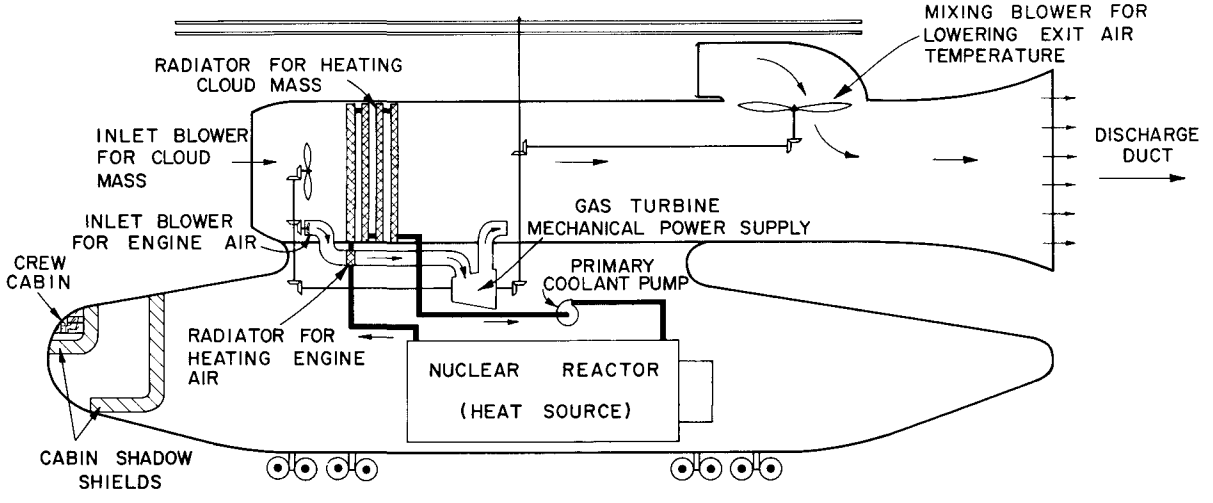

Fig. 8. A schematic drawing showing the layout for a hovering-type aircraft equipped with a nuclear heat source. The reactor has an indirect cycle in which a fluid is heated in the reactor and then pumped to radiators past which part of the cloud mass flows.

TABLE V. Calculation of cost of water delivered to site when precipitation is first postponed and then caused by airborne direct-heating system.

Size of heat source in each aircraft		2×10^3 Mw
Number of aircraft required		4
Cost for 4 aircraft	Fossil fueled	Nuclear fueled
Aircraft	$\$40 \times 10^6$	$\$40 \times 10^6$
Additional cost of nuclear reactor		$\$120 \times 10^6$
Annual fixed charge (15%)	$\$ 6 \times 10^6$	$\$ 24 \times 10^6$
Annual operating costs less fuel	$\$12 \times 10^6$	$\$24 \times 10^6$
Fuel costs (4 aircraft)		
Fossil fuel (160 000 BTU/gal) at \$0.10/gal	3.2×10^5	
Nuclear fuel at \$0.001/thermal kw-hr		1.5×10^5
Total cost for water delivered to site (2.6×10^8 gal)		
Fuel	$\$3.2 \times 10^5$	$\$1.5 \times 10^5$
Fixed charges (annual/360)	1.6×10^4	6.7×10^4
Operating (annual/360)	3.3×10^4	6.7×10^4
	$\$37 \times 10^4$	$\$28.8 \times 10^4$
Per 1000 gallons	\$1.40	\$1.10

cloud in Figs. 9 and 10. For the problem just calculated, the infrared system would require a radiator 20 m in diameter and almost 1 km long at 2000°K. It would of course be built as a number of units. The power input would be approximately 2×10^4 Mw since the over-all efficiency is only about 15%. An equivalent setup would be needed for causing precipitation.

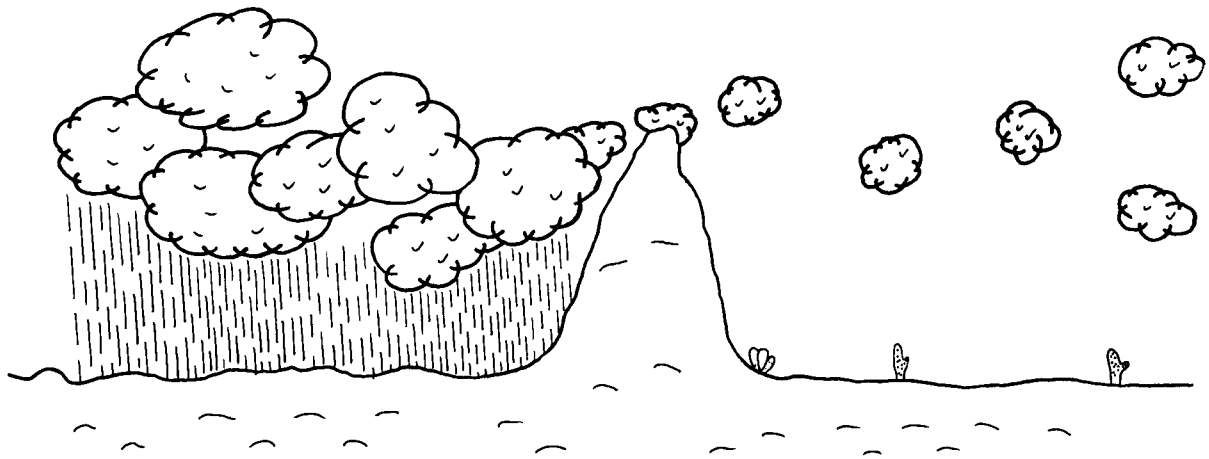

Fig. 9. Schematic diagram showing the behavior of a cloud as it approaches a mountain and is subjected to orographic lifting and resulting precipitation.

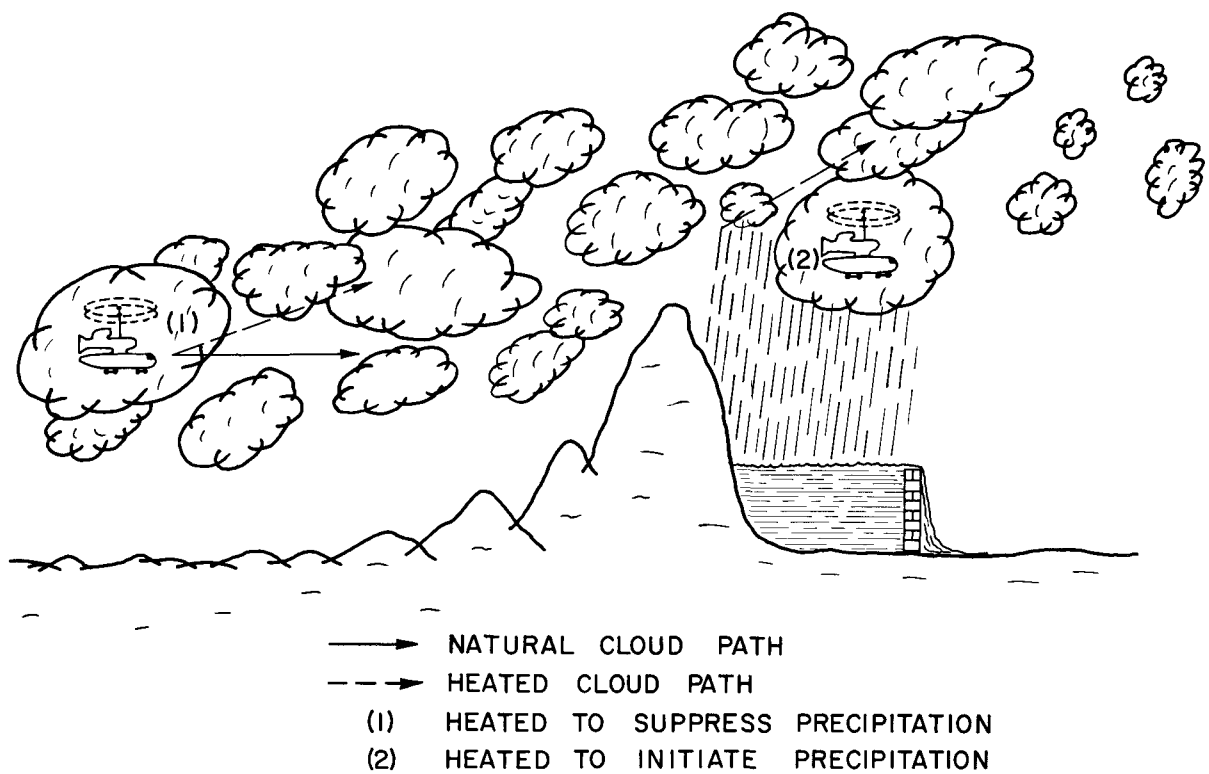

Fig. 10. Schematic drawing showing the use of a hovering-type aircraft as it applies heat at a stable rate to a cloud to cause it to rise gradually and pass over a mountainous area. At some location further down wind, the cloud is subjected to rapid heating to establish convective currents within the cloud with resulting precipitation.

It should be emphasized that the foregoing calculations are based on a number of assumptions about the response of a cloud system to heat. It is possible that we have been unduly pessimistic and that our cost estimate is seriously high because meteorological calculations are so uncertain. We are really arguing here that some small-scale experiments along the lines described are desirable.

PUBLICATIONS SINCE THE LAST REPORT

PAPERS

TRANSFER OF EXCITATION ENERGY IN SOLID SOLUTIONS OF ANTHRACENE-POLYSTYRENE AND 9,10-DIPHENYLANTHRACENE-POLYSTYRENE

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ABSTRACTS

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ROTATIONAL MODEL FOR Fe^{57}

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A CRANKED-MODEL THEOREM

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ADDITIONAL PAPERS ACCEPTED FOR PUBLICATION

NUCLEAR SPIN OF Ho^{166}

W. J. Childs and L. S. Goodman..... (Project I-80)
Phys. Rev. in April 15, 1961 issue.

ELECTRON BUNCHING IN THE MULTIPACTING MECHANISM OF HIGH-FREQUENCY DISCHARGE

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NUCLEAR ENERGY LEVELS OF Na^{24}. II

Carl T. Hibdon..... (Project I-98)
Phys. Rev. in May 15, 1961 issue.

LIFETIMES OF EXCITED STATES OF NUCLEI WITH ODD MASS

R. E. Holland and F. J. Lynch..... (Project I-14)
Phys. Rev. in March 1, 1961 issue.

CAPTURE OF SLOW NEUTRONS BY NUCLEI BOUND IN CRYSTALS

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A ROTATIONAL MODEL FOR Fe^{57}

R. D. Lawson and M. H. Macfarlane..... (Project V-10)
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DELAYED NEUTRONS FROM N^{17}

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..... (Project I-58)
Phys. Rev. in May 1, 1961 issue.

14.4-MEV (n,2n) CROSS SECTIONS

L. A. Rayburn..... (Project I-90)
In Phys. Rev.

ENERGY TRANSFER AND QUENCHING PROCESSES IN THE SYSTEM CHCLOHEXANE-BENZENE-TERPHENYL-OXYGEN

A. Weinreb..... (Project I-144)
J. Chem. Phys. in the March 1961 issue.

PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Institute Affiliates

(Assigned to the Physics Division from the International Institute of Nuclear Science and Engineering)

Dr. Sippanondha Ketudat, Thai Atomic Energy Commission, Thailand. Came to the Physics Division on November 4, 1960 to work with G. R. Ringo on anisotropies in the decay of the free neutron.

Dr. Eneas Salati, Escola Superior de Agricultura "Luiz de Queiroz", Sao Paulo, Brazil. Came to the Physics Division on February 8, 1961 to work with D. C. Hess on isotopic dating with a mass spectrometer.

Student Aide (Co-op)

Mr. John C. Pernicka, Illinois Institute of Technology. Working with W. J. Childs on development of a universal detector for the "old" (Mark I) atomic beam machine, and on the design and construction of a tuned rf amplifier. Came to ANL on February 6, 1961.

Student Aide (ACM)

Mr. Daniel Carson, Ripon College. Working with S. B. Burson on measurements to establish the decay scheme of Ho^{166}. Came to ANL on January 30, 1961.

Mr. Timothy R. Hart, Knox College. Working with S. S. Hanna on research with the Mössbauer effect. Came to ANL on January 30, 1961.

Mr. Norman Jesse, Ripon College. Working with S. Wexler on a study of the fragmentation of molecules by alpha ionization and on a search for transient ionic species resulting from ion-molecule reactions initiated by nuclear decay.

DEPARTURE

Dr. Arye Weinreb joined the Physics Division as a resident research associate on August 26, 1958. He has collaborated with L. J. Basile and W. L. Buck on the transfer of excitation energy in scintillating systems (Project I-144). He terminated at ANL on January 20, 1961 to return to the Hebrew University, Jerusalem .