The suggestion is also made that CO may be strongly
dissociated by the metastable Xe atoms (and H₂O somewhat
less strongly), thus producing oxygen atoms which
combine to form the O₂ molecules; (D(CO₂) = 5.5 v.
D(H₂O) = 5.0 v). If so, the fact that CO did not yield the
bands would indicate that the dissociation energy of CO is
greater than the energy of the upper metastable state of
Xe, namely 9.4 volts. (Energy of lower metastable state
equals 8.3 v.) This appears to be direct evidence in favor of
the 9.6-volt value of D(CO) as determined by Hagastrum and
Tate from appearance potentials in the mass spectro-
graph, or for the 11.11 v-value obtained in a recent spectral
analysis by Gaydon and Penney, but against the 9.14-volt
value determined from certain predissociation data. The
higher value appears to be more in accord also with
thermochemical data as brought out by Hagastrum and
Tate, and also by Asundi and Samuel.

Resonance Absorption by Nuclear Magnetic
Moments in a Solid

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IN the well-known magnetic resonance method for the
determination of nuclear magnetic moments by mo-
lecular beams, transitions are induced between energy
levels which correspond to different orientations of the
nuclear spin in a strong, constant, applied magnetic field.
We have observed the absorption of radiofrequency energy
due to such transitions, in a solid material (paraffin) con-
aining protons. In this case there are two levels, the
separation of which corresponds to a frequency, ω, near 30
megacycles/sec., at the magnetic field strength, B, used in
our experiment, according to the relation ω/2π = μB/μH. Al-
though the difference in population of the two levels is
very slight at room temperature (ω/kT ~ 10⁻⁴), the number of
nuclei taking part is so large that a measurable effect is to
be expected providing thermal equilibrium can be estab-
lished. If one assumes that the only local fields of import-
cance are caused by the moments of neighboring nuclei, one
can show that the imaginary part of the magnetic permea-
bility, at resonance, should be of the order ω/2kT. The
absence from this expression of the nuclear moment and the
interatomic distance is explained by the fact that the in-
fluence of these factors upon absorption cross section per
nucleus and density of nuclei is just cancelled by their
influence on the width of the observed resonance.

A crucial question concerns the time required for the
establishment of thermal equilibrium between spins and
lattice. A difference in the populations of the two levels is a
precondition for the observed absorption, because of the
relation between absorption and stimulated emission.

Moreover, unless the relaxation time is very short the
absorption of energy from the radiofrequency field will
equalize the population of the levels, more or less rapidly,
depending on the strength of this r-f field. In the expecta-
tion of a long relaxation time (several hours), we chose to
use a weak oscillating field that the absorption would
persist for hours regardless of the relaxation time, once
thermal equilibrium had been established.

A resonant cavity was made in the form of a short section
of coaxial line loaded heavily by the capacity of an end
plate. It was adjusted to resonate at about 30 mc/sec.
Input and output coupling loops were provided. The
inductive part of the cavity was filled with 850 cm³ of
paraffin, which remained at room temperature throughout
the experiment. The resonator was placed in the gap of the
large cosmic-ray magnet in the Research Laboratory of
Physics, at Harvard. Radiofrequency power was introduced
into the cavity at a level of about 10⁻⁴ watts. The radio-
frequency magnetic field in the cavity was everywhere
perpendicular to the steady field. The cavity output was
balanced in phase and amplitude against another portion
of the signal generator output. Any residual signal,
after amplification and detection, was indicated by a
microammeter.

With the r-f circuit balanced the strong magnetic field
was slowly varied. An extremely sharp resonance absorp-
tion was observed. At the peak of the absorption the
deflection of the output meter was roughly 20 times the
magnitude of fluctuations due to noise, frequency, insta-
bility, etc. The absorption reduced the cavity output by
0.4 percent, and as the loaded Q of the cavity was 670, the
imaginary part of the permeability of paraffin, at resonance,
was about 3·10⁻⁴, as predicted.

Resonance occurred at a field of 7100 oersteds, and a
frequency of 29.8 mc/sec., according to our rather rough
calibration. We did not attempt a precise calibration of the
field and frequency, and the value of the proton magnetic
moment inferred from the above numbers, 2.75 nuclear
magnetons, agrees satisfactorily with the accepted value,
2.7896, established by the molecular beam method.

The full width of the resonance, at half value, is about 10
oersteds, which may be caused in part by inhomogeneities
in the magnetic field which were known to be of this order.
The width due to local fields from neighboring nuclei had
been estimated at about 4 oersteds.

The relaxation time was apparently shorter than the
time (~ one minute) required to bring the field up to the
resonance value. The types of spin-lattice coupling sug-
gested by I. Waller are far by a factor of several hundred to
account for a time so short.

The method can be refined, in both sensitivity and
precision. In particular, it appears feasible to increase the
sensitivity by a factor of several hundred through a change
in detection technique. The method seems applicable to the
precise measurement of magnetic moments (strictly,
gyromagnetic ratios) of most moderately abundant nuclei.
It provides a way to investigate the interesting question of spin-lattice coupling. Incidentally, as the apparatus required is rather simple, the method should be useful for standardization of magnetic fields. An extension of the method in which the r-f field has a rotating component should make possible the determination of the sign of the moment.

The effect here described was sought previously by Gorter and Broer, whose experiments are described in a paper which came to our attention during the course of this work. Actually, they looked for dispersion, rather than absorption, in LiCl and KF. Their negative result is perhaps to be attributed to one of the following circumstances: (a) the applied oscillating field may have been so strong, and the relaxation time so long, that thermal equilibrium was destroyed before the effect could be observed—(b) at the low temperatures required to make the change in permeability easily detectable by their procedure, the relaxation time may have been so long that thermal equilibrium was never established.

The \( \gamma \)-Rays of Radium D

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December 13, 1945

For many years RaD was regarded as a radioactive substance which emits nuclear \( \beta \)-rays of very low energy and monochromatic \( \gamma \)-rays of quantum energy 46.7 kev. Just before the war, however, it was shown by Amaldi and Rasetti,1 using the method of selective absorption, that the radiation is complex, the well-known 46.7 kev line being accompanied by a much weaker component of energy 43 kev. Following the publication of this result, a systematic study of the subject was started in Paris with a very strong source of RaD of about 100 mC, extracted previously by Professors Irène Joliot-Curie and F. Joliot. The following is a brief summary of the main experimental results, obtained in the Curie Laboratory and in the Laboratory of Nuclear Chemistry in the difficult conditions which prevailed from 1942–1945. The results deal with the detailed structure of the \( \gamma \)-radiation, the absolute intensity of the different lines, and the nature of the \( \gamma \)-rays of quantum energy 46.7 kev.

In the region between 25 and 100 kev, the analysis made by the methods of selective absorption2 and crystal diffraction3 leads to the conclusion that RaD emits in this region four \( \gamma \)-lines \((A, B, C, D)\) and two lines of \( \beta \)-rays of K-83, the corresponding energy and intensity being given in Table I.

The existence of these six different radiations is confirmed by another series of experiments in which the corresponding quantum energies are determined by measuring the true range of the photoelectrons which they project in a Wilson chamber.4 This method also suggested the existence of an additional weak line at about 65 kev (x) and relatively intense radiations below 25 kev.

<table>
<thead>
<tr>
<th>( \gamma )-ray line</th>
<th>( E ) (kev)</th>
<th>( I ) (quanta per 100 disint.)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>((X))</td>
<td>((65 \pm 5))</td>
<td>(&lt;0.2)</td>
<td>((5))</td>
</tr>
<tr>
<td>(A)</td>
<td>(46.7 \pm 0.1)</td>
<td>(2.8 \pm 0.1)</td>
<td>((1, 2, 3, 5, 8))</td>
</tr>
<tr>
<td>(B)</td>
<td>(43 \pm 1)</td>
<td>(0.2 \pm 0.1)</td>
<td>((1, 2, 3, 5))</td>
</tr>
<tr>
<td>(C)</td>
<td>(37 \pm 1)</td>
<td>(0.2 \pm 0.1)</td>
<td>((1, 2, 3, 5))</td>
</tr>
<tr>
<td>(D)</td>
<td>(32 \pm 1)</td>
<td>(0.2 \pm 0.2)</td>
<td>((1, 2, 3, 6))</td>
</tr>
<tr>
<td>(E)</td>
<td>(22.2 \pm 0.6)</td>
<td>(1.0 \pm 0.5)</td>
<td>((5, 6))</td>
</tr>
<tr>
<td>(F)</td>
<td>(7.3 \pm 0.7)</td>
<td>(\sim 10)</td>
<td>((6, 7))</td>
</tr>
</tbody>
</table>

In order to study the region below 25 kev, experiments were made with a Wilson chamber operating at suitable low pressure.5 It was thus found that in addition to the \( L \) spectrum of element 83, there is a new \( \gamma \)-ray line \((E)\) of 23.2 \pm 0.6 kev. This line has thus almost exactly half the quantum energy of the principle line \((A)\) and would be confused in diffraction spectrum experiments with the second-order image of the \((A)\) line. Another very intense \( \gamma \)-ray line \((F)\) of 7.3 \pm 0.7 kev has been observed in the energy region below the \( L \) levels of element 83.6 This radiation has been observed previously by Droste7 who classified it as one of the components of the \( L \) spectrum of element 83. From the energy determinations in our present experiments, it seems more reasonable to regard it as a new \( \gamma \)-ray line.

In order to investigate the nature of the principle line \((A)\) we have determined the intensity of the conversion electrons of this radiation by the usual methods of magnetic \( \beta \)-ray spectrography and obtained the value 2.9 for the internal conversion coefficient, \( N_e/N \), in the \( L_i \) level.6,8 The comparison with the theoretical calculation of Fisk9 indicates that the 46.7 kev line is most probably a quadripole radiation. For other \( \gamma \)-rays there is no information available about their conversion electron\( s^{10}\) to permit similar deduction about their nature to be made.

I should like to thank Professors I. Joliot-Curie and F. Joliot for their continuous interest and help, and Drs. Frilley, Surugue, and Ouang, and Mr. Marty for their important contributions and friendly collaboration in the course of these investigations.

* Harvard University, Society of Fellows (on leave).
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