Water Vapor Absorption Lines in the Solar Spectrum between 8μ and 13μ*

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A GRATING map of the solar spectrum from 7 to 14 microns has been published by Adel[1] in which bands of carbon dioxide, ozone, nitrous oxide, water vapor, and HDO were identified. Besides these well-defined bands, other lines of medium and strong intensity occur with no apparent regularity throughout the entire region. Adel[2,3] has suggested that some of these lines are due to atomic transitions, and he has tentatively identified several with transitions between high energy levels of NaI and KI, finding fairly good frequency agreement. Benedict[4] has also found that many of these lines coincide with predicted lines in the water vapor spectrum.

This region of the solar spectrum has recently been remapped at Columbus, Ohio, using a 3600-line/inch grating, and a Perkin-Elmer thermocouple and a thirteen-cycle-per-second amplifier. An improved resolution has been obtained and many new lines discovered, although the main structure closely resembles that observed in the earlier work of Adel. In particular, the intense irregularly spaced lines were again a prominent feature. However, by comparison with a laboratory absorption spectrum, obtained with the same spectrograph, of an eight-meter path of steam at 110°C and near atmospheric pressure, it has now been possible to assign most of these lines definitely to water vapor. This assignment has been further verified by observing that the intensities of the lines in the solar spectrum vary with the amount of water vapor in the atmosphere, being much weaker on cold winter days than during the summer months.

The water vapor lines in this region are too weak to be observed with the absorption path lengths ordinarily used for laboratory spectra. They are intense in the solar spectrum because of the large amount of water vapor in the atmosphere. Most of them are undoubtedly lines arising from transitions between levels of high J values; most of those lying beyond about ten microns are probably pure rotational lines, while those at shorter wavelengths are lines of the ν_2 fundamental at 6.3μ.

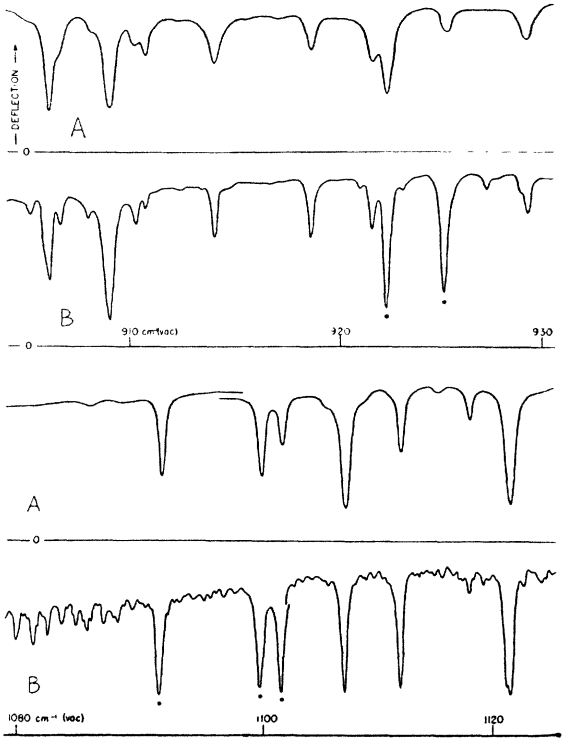

FIG. 1. Portions of the spectrum of an eight-meter path of steam at 110°C and corresponding portions of the solar spectrum. A. Water vapor spectrum. B. Solar spectrum.

In Fig. 1 two portions of these spectra are shown. The upper curves are parts of the laboratory spectrum of steam, and the lower curves are parts of the solar spectrum of the same regions. The lines which Adel tentatively identified as atomic in origin are marked with dots. The relative intensities of the water lines in the two spectra are sometimes different, and the lines are sharper in the solar spectrum. This is to be expected, since the steam was at 110°C which is considerably higher than the average temperature of the water vapor in the atmosphere.

With the identification of these water vapor lines in the solar spectrum, it is now believed that all the structure in the 8–13μ-region of this spectrum, with the possible exception of some weak lines, is due to the known atmospheric gases, water vapor, carbon dioxide, ozone, methane, and nitrous oxide.

A more complete description of both the solar spectrum and the water vapor spectrum between 7μ and 13μ is being prepared for publication.

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[1] A. Adel, Astrophys. J. **94**, 451 (1941).
[2] A. Adel, Astrophys. J. **94**, 449 (1941).
[3] A. Adel, *The Atmospheres of the Earth and Planets* (University of Chicago Press, Chicago, Illinois, 1949), p. 269, edited by C. P. Kuiper.
[4] W. S. Benedict, Symposium on Molecular Structure and Spectroscopy, The Ohio State University, Columbus, Ohio, June, 1950.

Evidence for an Excited State of He^5*

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A RECENT investigation of the energy spectrum of neutrons produced in the reaction of tritons with tritons has revealed two distinct groups of neutrons. These neutron groups are most reasonably accounted for by the assumption they arise from the reactions:

(a) $T+T \rightarrow He^5+n+10.53$ Mev;
(b) $T+T \rightarrow He^{5*}+n+7.9$ Mev.

The experiment consisted of bombarding tritium gas with tritons accelerated by the Los Alamos 2.5-Mev electrostatic generator. The neutrons were detected at 0° by means of 200-micron, Ilford C-2 photographic plates. The triton energy in the gas target varied from 906 kev to 426 kev due to target thickness. Recoil proton tracks within a cone of 10° centered around 0° were measured in the photographic emulsion. The neutron energy distribution shown in Fig. 1 was obtained after applying the known range-energy relationships in this type of emulsion and the $(n-p)$ cross section. A correction was made for the range dependence of the number of tracks which leave the emulsion. Although plotted every 250 kev, the points actually are computed on the basis of the relative number of neutrons per 500-kev

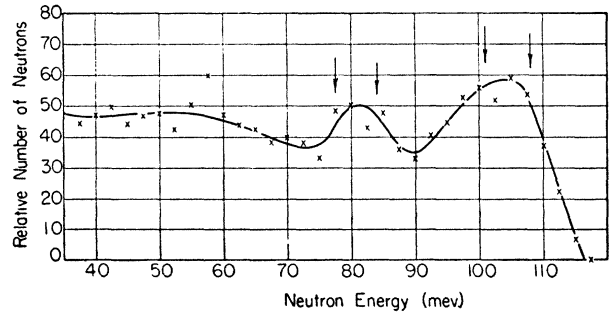

FIG. 1. Energy spectrum of neutrons from T+T reaction.

interval. The statistical uncertainty is about 15 percent. A background plate, obtained under identical conditions by accelerating tritons into the same target filled with He^4, indicated that the number of background neutrons over the complete spectrum was less than 1 percent.

One notices in Fig. 1 that two broad peaks appear at 10.4 and 8.1 Mev. We attribute these peaks to reactions (a) and (b), respectively. The corresponding ground state peak (a) has also been observed in the neutron spectrum obtained by Sanders, *et al.*[1] Although the variation of the incident triton energy was large, the high Q of the reaction greatly reduces the effect of the energy variation on the peak widths. The lines bracketing the peaks in Fig. 1 indicate the extent of peak broadening to be expected from the spread of incident triton energy. The remainder of the peak width is readily attributed to the finite resolution of the neutron detection system. The remainder of the neutrons are presumed to arise from various other possible reactions such as:

(c) $T+T\rightarrow He^4+n+n+11.4$ Mev;
(d) $T+T\rightarrow He^4+n^2+Q$;
(e) $He^5\rightarrow He^4+n+0.87$ Mev;
(f) $He^{5*}\rightarrow He^4+n+3.5$ Mev.

Reactions (e) and (f) represent the disintegration of the unstable He^5 formed in reactions (a) and (b). The occurrence of special interactions in the three particle disintegration could conceivably produce energy groups in the neutron spectrum. However, we feel that this possibility is a considerably less likely source of groups than the reactions (a) and (b). The greatest neutron energy expected from reactions (d), (e), and (f) occurs in reaction (f) and is less than 6.2 Mev. Consequently, these reactions would not contribute to the observed neutron energy groups at 10.4 Mev and 8.4 Mev.

The idea of He^5 having an excited state in the vicinity of 2.6 Mev above its ground state is not new nor inconsistent with previous results. As suggested by Goldstein,[2] a $P_{1/2}$ level above a $P_{3/2}$ ground state could provide satisfactory agreement between theory and the existing data on the low lying levels of He^5 as obtained from n-He^4 scattering.[3-6] Adair[7] reports that his analysis of the n-He^4 total cross-section measurements of Bashkin *et al.*[8] indicates the existence of a widely spaced inverted doublet in He^5.

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[1] Sanders, Allen, Almquist, Dewan, and Pepper, Phys. Rev. **79**, 238 (1950).
[2] H. Goldstein, Phys. Rev. **79**, 740 (1950).
[3] H. Staub and H. Tatel, Phys. Rev. **58**, 820 (1940).
[4] H. H. Barschall and M. H. Kanner, Phys. Rev. **58**, 590 (1940).
[5] T. A. Hall and P. R. Koontz, Phys. Rev. **72**, 196 (1947).
[6] T. A. Hall, Phys. Rev. **77**, 411 (1950).
[7] R. K. Adair, private communication.
[8] Bashkin, Petrie, and Mooring, Phys. Rev. **82**, 378 (1951).

Scattering of Thermal Neutrons by Mercury

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THERMAL neutron scattering by mercury should be strongly affected by the resonance[1] at -2.0 ev. In particular, one would expect a large positive coherent scattering length. We have recently measured three thermal cross sections of mercury: σ_{coh} (coherent scattering), $\sigma_{th\text{-}s}$ (total scattering), and $\sigma_{th\text{-}a}$ (absorption). In addition, we have measured the potential scattering cross section, σ_p, near thermal (19.5 ev). These data have been used to calculate the -2.0 ev resonance parameters in Hg^{199} in an attempt to assign a compound angular momentum value (J) to the capturing level.

The coherent scattering cross section is not easily measured by crystal diffraction schemes because of the high thermal absorption cross section (370*b*). Instead, it was measured by finding the critical wavelength for reflection of a beam of thermal neutrons incident on a surface of liquid mercury at a given angle. Observations were made at two angles, using a time-of-flight velocity selector.[2] An additional observation was made at a third, larger angle by comparison of intensities with the first two angles. The critical wavelength and the angle determine the index of refraction, which in turn determines the coherent scattering amplitude.[3] Results are given in Table I. From this it can be seen that mercury

TABLE I. Observed coherent scattering cross section of Hg for thermal neutrons.

Angle (min)	Wavelength (angstroms)	σ_{coh} (barns)
8.29	1.84	22.1
12.25	2.63	24.8
20.22	4.70	18.4
		av 21.5±2

makes a particularly good neutron mirror. The surface is easy to prepare and is stable for at least several days with only ordinary care.

It is appropriate to take an average value of σ_{coh} since no energy dependence is to be expected, and none is observed.

Measurement of $\sigma_{th\text{-}s}$ was done with the use of a 4π-annular neutron scattering counter.[4] The counter is provided with an axial hole through which a neutron beam from the pile may pass. A scattering material is placed transverse to the beam on the axial center of the counter. Known thicknesses of gold-mercury amalgam and vanadium metal foil were placed separately in the counter, and their counting rates compared. The effect of gold scattering was subtracted after observing the counting rate from a gold foil of the same thickness as that used in the Au-Hg amalgam. Vanadium was chosen as a standard ($\sigma_{th\text{-}s}=\sigma_{inc}=5.00$ barns) since thermal neutron scattering from vanadium is almost entirely incoherent.[5] This and the mercury amalgam minimize diffraction effects. $\sigma_{th\text{-}s}$ (Hg) so obtained was 26.5 ± 0.1 barns.

By using a resonance beam, placing a resonance neutron scattering detector[6] of W^{186} in the annular counter, and observing the transmission of Hg, σ_p was measured at 19.5 ev. The value obtained was 13.3 barns. This is in good agreement with σ_p measurements at 120 ev and 350 ev.[7] The thermal absorption cross section, $\sigma_{th\text{-}a}=370$ barns, was taken from recent pile-oscillator measurements.[8]

If one assumes $4\pi R^2=13.3$ barns where R is the nuclear radius (spin independent and identical for all isotopes), one can calculate the resonance parameters for the -2.0-ev level as well as σ_{coh}. A one-level Breit-Wigner set of formulas is assumed. The results of this calculation are given in Table II.

TABLE II. Resonance parameters for the -2.0-ev level of Hg, and calculated coherent scattering cross section, for $J=0$ and $J=1$.

	$J=0$	$J=1$
Γ_n	0.053 ev	0.027
$\Gamma\gamma$	0.225 ev	0.149
Γ	0.278 ev	0.176
σ_{coh}	17.1	20.0

One sees here a definite preference for the case $J=1$, though the case $J=0$ cannot be ruled out with certainty.

Hg^{199} has spin $\frac{1}{2}$ and on neutron capture goes to Hg^{200}, an even-even nucleus with ground-state angular momentum equal to zero. An interesting consequence of the value of J for the compound capture state had to do with the resulting cascade γ-ray spectrum. A γ-ray transition of energy equal to binding in Hg^{200} is forbidden for $J=0$ and allowed for $J=1$. Furthermore, the first transition in the cascade is usually of sufficient energy that no other γ-ray will