TABLE I. Wavelengths and relative intensities of H_2O^{16} millimeter wavelength absorption lines.

Transition	Wavelength (mm)	Relative intensity
$5_{-1}-6_{-5}$	13.48	1
$15_{-9}-14_{-3}$	2.6 ±0.2	3.3×10^{-4}
2_2-3_{-2}	1.63 ±0.02	1.9×10^{2}
$14_{-8}-13_{-2}$	1.3 ±0.2	1.4×10^{-3}
$16_{-10}-15_{-4}$	1.2 ±0.2	1.6×10^{-4}

calculations. Recent rotation-vibration spectrum measurements[7] have revised and extended this listing, and with these tables three additional lines are predicted; their wavelength and peak intensities—estimated relative to that of the 13.48-mm transition—are given in Table I. None are very close to the $5_{-1}-6_{-5}$ transition,[8] and because of their weak intensities cannot influence the over-all theoretical absorption values.

Using these same energy-level tables, the absorption at 13.5 mm arising from all lines at shorter wavelengths has been calculated. Van Vleck's estimate that inclusion of contributions from levels higher than $J=6$ would be of negligible importance in this region has been thereby verified; this "residual" absorption term is increased by only some 2.1 percent over his value.

With new HDO ground-state term values[9] complete through $J=12$, augmented by several measured microwave lines,[10] the absorption spectrum for this water-vapor form has been calculated. In its naturally occurring abundance, absorption values of over 5 percent that of H_2O are reached at several points in the cm-mm region; at 13.5 mm, however, the ratio of HDO to H_2O total absorption is only 0.3 percent.

Because of their structural symmetry identity with H_2O^{16}, the other isotopic forms H_2O^{17} and H_2O^{18} are not present as "additional" lines in the manner of HDO. Their calculated energy-level shifts from those of H_2O^{16} are too small to permit increased absorption near 13.5 mm. These heavy oxygen isotope spectra are similar to that of H_2O^{16} with the lines shifted somewhat and reduced in intensity, corresponding to their smaller natural concentration. Mass substitution calculations (ignoring centrifugal-distortion energy changes) indicate that the $5_{-1}-6_{-5}$ H_2O^{18} line will appear near 5.5 mm at about 4 percent of the H_2O^{16} intensity at that wavelength.

The influence of D_2O is negligible because of its extremely small abundance.

It can be concluded, therefore, that an explanation for the experimental-theoretical discrepancy in absolute absorption intensity cannot be found in a more complete calculation of the water-vapor spectrum (see Fig. 1). Variations in line-to-line collision half-width now appear to exist for the water molecule,[2,11] and such variation should be studied as an alternative explanation because of its importance in the far-wing term. Recent measurements in the ammonia low-frequency far wing, however, show an absorption higher by some 30–40 percent than calculated, even though line-width variation is taken into account,[12] and the failure of the impact theory to predict accurate absorption values far from resonance must also be considered.

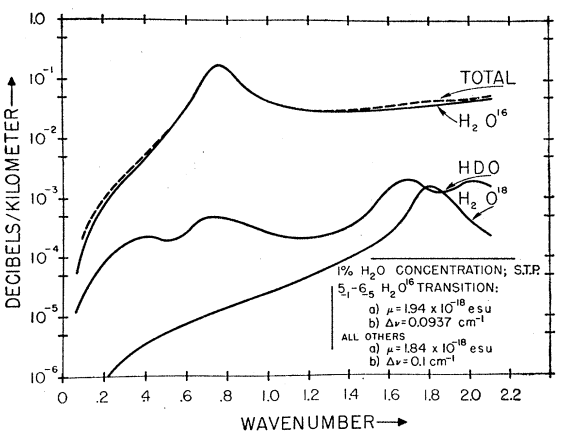

FIG. 1. Water-vapor absorption in the one-centimeter wavelength region.

The author is grateful to Margaret Hill, who performed most of the calculations referred to here, and to M. W. P. Strandberg for helpful discussions.

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[9] A prepublication listing of these energy-level values was very kindly furnished the author by Dr. E. K. Plyler of the National Bureau of Standards. See Benedict, Gailar, and Plyler, J. Chem. Phys. **21**, 1301 (1953).
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Total Cross Section of Pions at 1.5 Bev*

R. L. COOL, L. MADANSKY,† AND O. PICCIONI
Brookhaven National Laboratory, Upton, Long Island, New York
(Received November 9, 1953)

THE total cross sections of negative pions on hydrogen and the deuterium-hydrogen difference have been measured for a pion kinetic energy of 1.5 Bev. The pions were produced in the Brookhaven Cosmotron by bombarding a beryllium target with the 2.3-Bev proton beam. The negative mesons emitted in the forward direction were deflected by the Cosmotron magnet into a 6-in.×6-in. channel in the 8-ft thick concrete shield. The beam outside the shield was defined by a telescope of two liquid scintillation counters in front of a deflecting magnet and two behind (see Fig. 1). The magnetic analysis of the beam agreed very well with the incident momentum of 1.7 Bev/c with a spread of ~20 Mev/c as expected from graphical analysis of the dispersion of the Cosmotron magnet. The ionization loss in the CH_2 absorber is ~120 Mev/c. A large fifth counter was placed behind counter four at various distances. Fourfold and fivefold coincidences were recorded to measure the attenuation of the beam in absorbers placed between counters four and five. The resolution time of the circuits at half-maximum was $\pm3\times10^{-9}$ sec which is $\sim10^7$ times smaller than the duration of the Cosmotron pulse.[1] Accidentals were always found negligible. Typical counting rates were 5 to 10 sec^{-1}, with a repetition rate of 0.2 sec^{-1}.

The muon contamination was determined by filtering out the pions by virtue of their nuclear interaction, which is absent for muons. Thus, an absorption curve in Fe up to 495 g cm^{-2} shows an attenuation of about a factor of 50 for the pions and allows the muons to be evaluated as 5.4 percent of the incident beam. Uncertainty in the calculation of the multiple Coulomb scattering and the difference between the extreme limits for the absorption coefficient for pions lead to an error of ±1.7 percent. The electron contamination has been measured to be less than 1 percent by an arrangement detecting electron showers produced in Pb (~30 electrons at shower maximum).

The cross section in hydrogen $\sigma(\pi^-,p)$ was obtained by measuring the CH_2-C difference (8.27 and 12.17 g cm^{-2} hydrogen); similarly, $\sigma(\pi^-,d-p)$ by heavy-water–water difference (6.78 g cm^{-2} hydrogen). Since total cross sections determined from

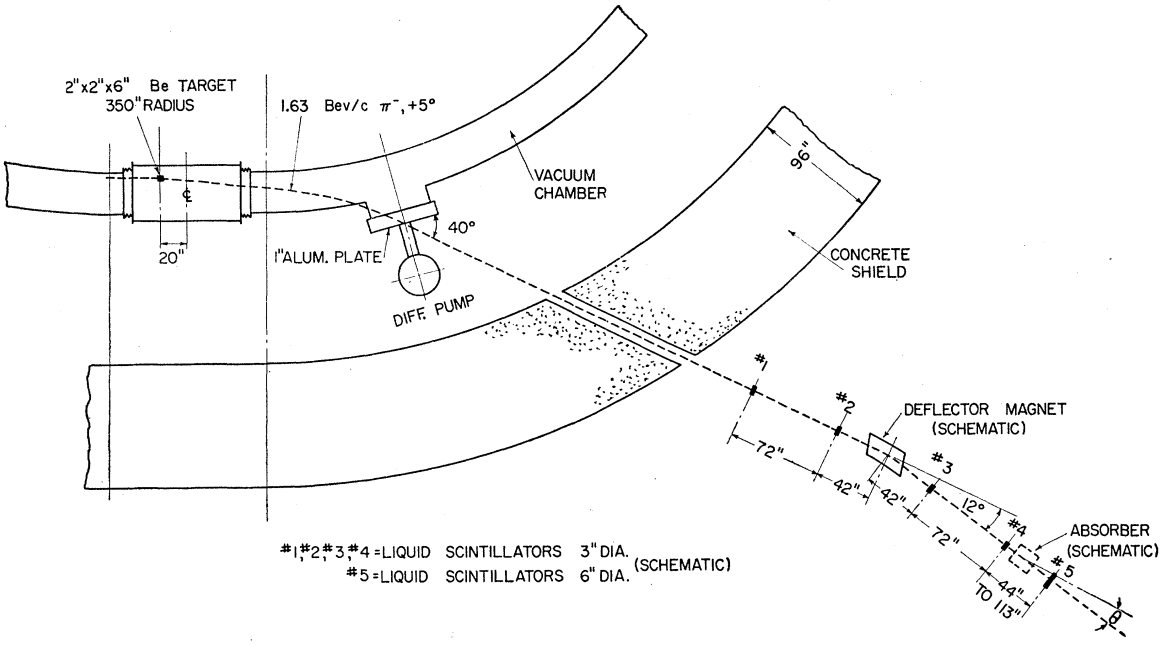

FIG. 1. Experimental arrangement.

attenuation experiments may have an appreciable dependence on the angle within which secondaries from the interactions can cross the last counter, different experiments have been made with various geometries which we characterize by the rms value $\theta_{\rm rms}$ of the semi-aperture of the angular cone subtended by the last counter at the absorber. Table I shows the results obtained. The errors quoted include uncertainties other than the statistical error, such as those present in the muon contamination. By observing the effect of thin Pb plates inserted between the slabs of the carbon absorber, the effect of the multiple Coulomb scattering in hydrogen was determined. The largest correction, ~3 mb, was found for the $\theta_{\rm rms}=1.8°$ geometry. The large-angle, single Coulomb scattering in hydrogen was computed to be negligible. No such corrections are manifestly necessary for the D_2O-H_2O difference.

Table I shows some probable dependence of the cross sections on $\theta_{\rm rms}$, which could be interpreted as the result of secondary particles, possibly elastically scattered pions, projected close to the forward direction. Clearly, the value for $\theta_{\rm rms}\leqslant 2.5°$ can be taken for the total cross section; it is, after correction, $\sigma(\pi^-,p)=34\pm3$ mb. In the same fashion, $\sigma(\pi^-,d-p)=29\pm3$ mb. This latter value can be interpreted as approximately the cross section for negative pions on neutrons, $\sigma(\pi^-,n)$ on the assumption that at these energies ($\lambda\sim2\times10^{-14}$ cm) and for values of the cross section quite smaller than $\pi(\hbar/\mu c)^2=61$ mb, $\sigma(\pi^-,d)$ is close to the sum $\sigma(\pi^-,p)+\sigma(\pi^-,n)$. If one further assumes that charge symmetry holds, our measured value of $\sigma(\pi^-,d-p)$ could be considered as approximately equal to $\sigma(\pi^+,p)$.

TABLE I. The total cross section of 1.5-Bev negative pions.

$\theta_{\rm rms}$	1 $\sigma(\pi^-,p)$ millibarns (uncorrected)[a]	2 $\sigma(\pi^-,p)$ millibarns (corrected)[a]	3 $\sigma(\pi^-,d-p)$ millibarns
7°	30 ±2	···	25.6±4
4.5°	33.7±3	···	···
2.5°	36 ±3	34 ±3	28.7±3
1.8°	35.5±3	32.5±3	···

[a] The values of column 1 are uncorrected for multiple Coulomb scattering loss of pions by hydrogen. The values of column 2 are corrected for this effect.

We are very grateful to Dr. G. B. Collins, Dr. G. K. Green, and to the entire Cosmotron Staff for their continuous cooperation and to Dr. H. S. Snyder for valuable discussions.

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† On leave from Johns Hopkins University, Baltimore, Maryland.
[1] For increasing the pulse duration up to 20–30 millisec, we are especially indebted to H. S. Snyder.

The Natural Tritium Content of Atmospheric Hydrogen*

A. V. GROSSE AND A. D. KIRSHENBAUM
Research Institute of Temple University, Philadelphia, Pennsylvania
AND
J. LAURENCE KULP AND W. S. BROECKER
Lamont Geological Observatory, Columbia University, Palisades, New York
(Received November 16, 1953)

RECENTLY the existence of natural tritium in Norwegian surface waters was demonstrated.[1] This was accomplished by enriching the natural tritium content by electrolysis between 1 and 10 million-fold. Faltings and Harteck[2] in Germany have approached this problem in a more daring manner by assuming that the molecular hydrogen, which is present in the air by about 0.5 ppm would contain cosmic-ray tritium in a much higher concentration than in atmospheric water. They assumed that the tritons produced by cosmic radiation in the uppermost part of the atmosphere would be trapped essentially in molecular hydrogen since at this altitude (~70 km) water is photochemically decomposed by ultraviolet radiation into atoms of hydrogen and oxygen. They were able to detect the natural tritium in a sample of hydrogen which was first isolated as water and then isotopically enriched. The effect due to the tritium, however, was only 10 percent above the counter background yielding an estimated T/H of 10^{-14}.

With superior techniques at hand it was thought desirable to examine the tritium content of the molecular hydrogen in a sample of ground-level air in America. Thanks to the cooperation of Dr. C. O. Strother[3] we were able to obtain 25 cc of water produced