ABSORPTION COEFFICIENTS FOR HOMOGENEOUS X-RAYS.

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SYNOPSIS.

Absorption Coefficients of Various Organic Liquids for X-rays of Wave-length 0.715 Å.—By means of a spectrometer with narrow lead slits and a calcite crystal, the K_α radiation from the Mo target of a Coolidge tube was reflected into an ionization chamber, and the effect of interposing a cell containing a known thickness of liquid before the first slit, was measured. Thus absorption coefficients were determined for carefully purified samples of *pinene* ($C_{10}H_{16}$), *limonene* ($C_{10}H_{16}$), *benzene* (C_6H_6), *toluol* (C_7H_8), *isopropyl alcohol* (C_3H_8O), *methyl proprionate* ($C_4H_8O_2$), *ethyl acetate* ($C_4H_8O_2$), *acetone* (C_3H_6O), *ethyl formate* ($C_3H_6O_2$) and *trimethylene glycol* ($C_3H_8O_2$).

Atomic absorption coefficients for C, H, and O for X-rays of wave-length 0.715 Å. were computed from the above data, assuming absorption to be an additive atomic property, and came out from 11.00 to 11.55 $\times 10^{-24}$ for C, 0.45 to 0.50 $\times 10^{-24}$ for H and 29.9 to 31.0 $\times 10^{-24}$ for O. Using the mean values, the computed coefficients are within $\frac{1}{3}$ per cent. of the observations, on the average. But the fact that the computed values for acetone and water are 1 per cent. too low suggests that the *assumption that absorption is an atomic property* may not be accurately true.

THIS research was undertaken to obtain new data upon the absorption of x-rays because of the great variation in the results obtained by different investigators. The work of Hull,[1] Richtmyer and Grant,[2] Richtmyer,[3, 4] Hewlett[5] and Bragg[6] has shown that for homogeneous x-rays the absorption is proportional to the cube of the wave-lengths of the incident radiation. This emphasizes the desirability of working with as near pure monochromatic radiation as possible.

In this work the author proceeded first to determine the molecular absorption of several organic compounds. If one assumes an additive relation for molecular absorption it is then possible to determine the atomic absorptions of the constituent elements. In this way the atomic absorption coefficients were determined for hydrogen, carbon and oxygen for the wave-length 0.715 Å.

[1] PHYS. REV., Vol. 8, p. 326, 1916.
[2] PHYS. REV., Vol. 15, p. 547, 1920.
[3] PHYS. REV., Vol. 17, p. 264, 1921.
[4] PHYS. REV., Vol. 18, p. 13, 1921.
[5] PHYS. REV., Vol. 17, p. 284, 1921.
[6] Phys. Mag., Vol. 28, p. 626, 1914.

The molecular absorption is defined as that fraction of the incident radiation which is absorbed per molecule per square centimeter of surface normal to the direction of the pencil of rays. In this work the absorption means the total decrease of the incident radiation which includes the "true absorption" and the scattering effect. The molecular absorption was computed from the mass absorption through the relation,

$$M = \frac{\mu}{\rho} m,$$

where M represents the absorption of the molecule,
m represents the actual mass of the molecule,
μ represents the absorption of substance as determined,
ρ represents the density of substance used.

In this computation the mass of the hydrogen atom has been taken as 1.64×10^{-24} gms.

The hydrocarbons used for the determination of the atomic absorptions of hydrogen and carbon were pinene, limonene, benzene and toluol. The atomic absorptions were then determined from two simultaneous equations involving the molecular absorptions of two different compounds. For example the following equations:

$$10\mu_c + 16\mu_H = 1.209 \times 10^{-22},$$
$$6\mu_c + 6\mu_H = 0.707 \times 10^{-22}.$$

Apply to pinene and benzene respectively, μ_c and μ_H representing the atomic absorptions of carbon and hydrogen and the right members representing the molecular absorptions of the compounds.

Having determined the atomic absorptions of hydrogen and carbon the absorption of the oxygen atom was determined from the molecular absorptions of several organic compounds containing oxygen.

METHOD.

The general method of making these measurements did not involve any essentially new principle. The radiation used was that of the K_α line from a molybdenum-target Coolidge tube. The radiation first passed through two very narrow lead slits which limited the divergence of the beam to a few minutes of angle. The emergent radiation was then incident upon a calcite crystal set at the proper angle to reflect the K_α line in the first order. After reflection the radiation passed through another slit into the ionization chamber.

The central electrode of the ionization chamber was supported in a bakelite insulator and connected to the leaf of a Bumstead electroscope.

Methyl iodide or ethyl bromide was used to increase the ionization. Considerable difficulty was experienced with leakage when the vapor density approached that of saturation. By using an ionization chamber approximately 70 cms. long sufficient ionization was produced when the vapor density was low in which case the leak became negligible or could easily be corrected for. The intensity of radiation was measured by the rate of change of potential of the central electrode as indicated by the electroscope.

The various solutions were held in a small bakelite cell while the absorption determinations were being made. This cell was placed in front of the first slit and in this way scattered radiation was prevented from entering the ionization chamber.

The filament of the tube was maintained at a constant temperature by a set of storage batteries while the potential across the tube was supplied by a 5 KVA high-tension transformer. Since the primary voltage was supplied from the mains small variations of potential across the tube were unavoidable. To make the effect of this variation as small as possible the data were taken in a continuous series of observations lasting over a considerable time. In this way the error due to the fluctuations of potential tended to eliminate itself in the mean of several observations.

The absorption was computed from the following formula,

$$\mu = \frac{2.30}{d} \log_{10} K \frac{T_x}{T_0},$$

where d represents the thickness of the absorber, T_x and T_0 the times required to change the potential of the system to some constant and arbitrary value with and without the absorber and K the fraction of the incident energy transmitted by the empty cell.

RESULTS.

From the data taken the molecular absorption was computed from the relation previously given. The following table gives the results directly obtained from the data for the hydrocarbons.

Compound.	μ.	Molecular Absorption $\times 10.^{24}$
Pinene, $C_{10}H_{16}$	0.464	1.209
Limonene, $C_{10}H_{16}$	0.457	1.206
Benzene, C_6H_6	0.485	0.707
Toluol, C_7H_8	0.477	0.834

From these different compounds various sets of simultaneous equations may be written and from them the atomic absorption of carbon can be determined. These values for the absorption of the carbon atom together with the different combinations of the compounds used are as follows:

Benzene—Pinene	0.1132×10^{-22}
Benzene—Limonene	0.1137×10^{-22}
Benzene—Toluol	0.1100×10^{-22}
Toluol—Limonene	0.1155×10^{-22}
Toluol—Pinene	0.1148×10^{-22}
Mean =	0.1134×10^{-22}

Knowing the absorption of the carbon atom it was then possible to get the absorption of the hydrogen atom from the molecular absorption of each of the hydrocarbons used. The values obtained for hydrogen from the different compounds are, pinene 0.0050, limonene 0.0045, benzene 0.0045 and toluol 0.0047. In each case the numerics are multiplied by 10^{-22}.

The results obtained for the atomic absorption of oxygen and the compounds from which they were obtained are given below.

Substance.	μ.	Molecular Absorption.	Atomic Absorption of Oxygen.
Isopropyl Alcohol, C_3H_8O	0.544	0.683×10^{-22}	0.304×10^{-22}
Methyl Proprionate, $C_4H_8O_2$	.698	1.089	0.299
Ethyl Acetate, $C_4H_8O_2$	.684	1.099	0.304
Acetone, C_3H_6O	.563	0.679	0.310
Ethyl Tomate, $C_3H_6O_2$	.737	0.970	0.301
Trimethylene Glycal, $C_3H_8O_2$	.833	0.986	0.304

Mean = 0.304×10^{-22}.

A summary of all results obtained by the author and those obtained by others are included in the following table.

Preliminary experiments showed the necessity of specially prepared chemical compounds to avoid the impurities which are often present in materials supposed to be pure. In the preparation of the hydrocarbons the author commenced with relatively pure samples of pinene, limonene and benzene and further purified these through repeated distillation or crystallization. The toluol used was not further purified but since it gave results in agreement with those obtained from the other compounds the results are likewise included in the tables. The oxygen compounds were specimens very carefully purified by Mr. G. A. Ramsdell of the department of chemistry and left little to be desired in their purity.

Substance.	Observers.			
	Hewlett.	Richtmyer.	Windgårth.	Taylor.
Carbon, μ/ρ	0.551		0.667	
μ_a*	0.1084[2]		0.1313[2]	0.1134
Oxygen, μ/ρ	1.126		1.000	
μ_a	0.295[2]		2.62[2]	0.304
Hydrogen, μ_a	0.011[1]			0.0048
Aluminum, μ/ρ	5.17	5.32	5.28	5.15
μ_a	2.30[2]	2.37[2]	2.36[2]	2.29
Water, μ/ρ	1.073	1.129	1.013[2]	1.089
μ mol	.317[2]	0.333		0.322
Acetone, μ/ρ			0.786	0.714
μ mol			.748[2]	0.679

μ_a* Written for atomic absorption.

The high value obtained by Windgårth for the absorption of oxygen is probably due to an impurity of high atomic weight. The molecular absorption of acetone as determined by that investigator is considerably higher than the value obtained by the writer. Acetone and many other organic compounds absorb moisture from the air and unless used soon after preparation will cause an error depending upon the amount absorbed.

From the data it is seen that two pairs of isomers have been used. Within the limit of the experiment the molecular absorptions are the same for the compounds of the same composition and offer additional evidence in favor of the view that x-ray absorption is an atomic property. In the case of oxygen however there seems to be a difference between the atomic absorption of oxygen as determined by Hewlett using liquid oxygen and that determined from oxygen compounds in this investigation which is somewhat greater than the error of measurements. Whether there is any significance to this small difference can only be determined by additional work in which the same investigator uses both forms of oxygen. Some doubt may also be cast upon the belief that x-ray absorption is a property of the atom only when one considers the absorption of hydrogen as determined in this research. From the measurement of the molecular absorptions of four hydrocarbons the atomic absorption of

[1] Computed from author's data on water and oxygen.

[2] Computed from author's data.

[3] Computed from author's data from value for $\lambda = .430$ Å. by the relation $\mu/\rho = K\lambda^3 + \sigma/\rho$.

hydrogen was found to be 0.0048×10^{-22}. When the atomic absorption of oxygen 0.304×10^{-22} is subtracted from the molecular absorption of water, 0.322×10^{-22} a value is found for the absorption of hydrogen approximately twice that as determined from the hydrocarbons. This difference in the absorption of the hydrogen atom seems considerably greater than the experimental error would account for. This apparent difference in the absorption of hydrogen in water and in hydrocarbons might be caused by a difference in the strength of the bond uniting the hydrogen to the other elements of the compound. This seems the most probable when one realizes the extreme stability of the hydrocarbons and the ease with which water is broken up.

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