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OPTICAL ABSORPTION SPECTRA OF SOME POTENTIALLY INTERESTING GASES FOR CHERENKOV COUNTERS*

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For gas Cherenkov counters employing wavelength shifters coupled to normal-glass phototubes, the vacuum ultraviolet transmission of the filler gas is of great interest. We have measured transmission to 1100 Å for an optical path of one atmosphere-meter of methane, ethane, Freon 14, propane, butane, isobutane, nitrogen, sulfur hexafluoride, Freon 22, and methyl chloride. Aging results on wavelength shifters are reported.

1. Introduction

The use of Cherenkov counters is widespread and essential in many areas of high-energy physics. Use of quartz-windowed photomultiplier tubes enables the experimenter to use Cherenkov light from the visible to almost 2000 Å. Recently the feasibility of using organic wavelength shifters in conjunction with normal-glass phototubes was successfully demonstrated[1]). The effect of exposure of MgF_2-coated samples of p-terphenyl and diphenyl stilbene to different gaseous environments was investigated. The gases were nitrogen, oxygen and propane, at a pressure of about 2 atm absolute. Within the experimental error (±10%) no aging effects could be detected over a period of three months. These wavelength-shifter materials convert photons in the wavelength range of 1100 to 3600 Å into an emission centered around 3850 Å. In view of this possible extension of the useful Cherenkov light range of 1100 Å, it is of special interest to find potential gas fillers which might be transparent to light below 2000 Å. In this paper, we report absorption spectra of some of these gases in the vacuum UV region.

2. Experimental

The usual method of measuring gas absorption in the vacuum UV range involves filling an appropriate LiF-windowed absorption cell with the gas of interest. These cells are available with only small optical paths, and they cannot be highly pressurized because of the fragility of the LiF windows. Since the objective of our experiments was to find the absorption properties of the gases in Cherenkov counter conditions, i.e., long optical paths (1 m) and relatively high pressures (at least 1 atm), use of the commercially available cells would have involved large extrapolation with concomitant inaccuracies.

The measurements were performed in a McPherson Model 225 Vacuum UV Monochromator in the following way: The H_2 light source was sealed with a LiF window and connected to the monochromator, which was filled with the gas of interest at a maximum pressure of 700 torr. The light intensity transmitted through 1-m optical path of gas was recorded as a function of wavelength. This intensity was compared with the intensity of the light transmitted through the monochromator under vacuum conditions. The absorption spectrum of the gas at a pressure of 760 torr was found from the relationship:

$$\frac{A_1}{A_2} = \frac{P_1}{P_2},$$

where A_i is the optical density for a pressure P_i of gas. The monochromator was not filled to 760 torr because there even slight fluctuations in the pressure would cause O_2 contamination.

The absorption data on Freon 22 and methyl chloride were obtained with a Beckman DK 2A Ratio Recording Spectrophotometer using a high pressure UV cell[2]). Fused silica windows identical to the windows of the cell were placed in the reference beam. The entire instrument was continuously flushed with nitrogen during the measurements.

3. Results

The transmission of 1 atm m of methane, Freon 14, propane, and ethane are given by curves (a), (b), (c), and (d) of fig. 1. Methane was Matheson chemical

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purity grade, propane was Matheson instrument grade, ethane was Matheson chemical purity grade, and Freon 14 (minimal purity 99.7%) was also manufactured by Matheson. While the chemical purity grade methane is very satisfoctary, ethane of the same grade (i.e., same percentage of impurity) contains impurities such as ethylene and propylene that cause a considerable deterioration of its transmission properties.

In fig. 2, curves (a) and (b) show the respective transmission of isobutane and butane. Both of the gases are of Matheson instrument grade. Since both have the same index of refraction, it is very clear that isobutane is the superior Cherenkov counter filler. The likely cause for the much inferior transmission of butane is the presence therein of higher members of the aliphatic series, such as 2,2 dimethylpropane and isopentane.

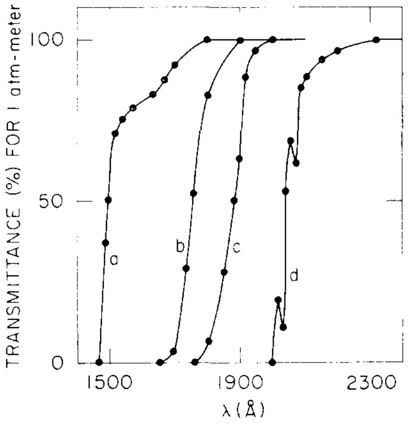

Fig. 1. Curve a: transmission of 1 atm m chemical purity grade methane. Curve b: transmission of 1 atm m Freon 14 (minimal purity 99.7%). Curve c: transmission of 1 atm m instrument grade propane. Curve d: transmission of 1 atm m chemical purity grade ethane.

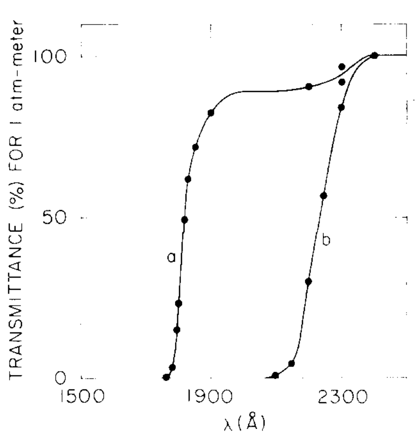

Fig. 2. Curve a: transmission of 1 atm m instrument grade isobutane. Curve b: transmission of 1 atm m instrument grade butane.

Fig. 3 represents the transmission of 1 atm m of nitrogen. The nitrogen gas was obtained by evaporation from a liquid nitrogen dewar. Since nitrogen is known to be a very good scintillator[3]), the possibility that the transmitted light includes nitrogen fluorescence was eliminated as follows: The spectrum of the lamp was scanned very carefully between 3000 and 6000 Å[4]), and compared with the spectrum obtained in the absence of N_2. No significant differences were found.

Fig. 4 shows the transmission curves for SF_6 of different grades obtained from two manufacturers. Neither purity is satisfactory since the measured values are near 1750 Å and 1850 Å, respectively, while the expected upper limit of the absorption is around 14Å70. This absorption edge was calcûlated in the

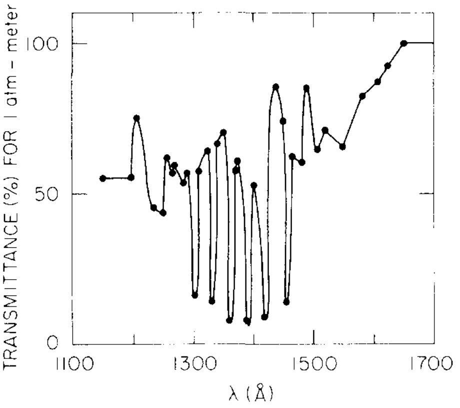

Fig. 3. Transmission of 1 atm m nitrogen.

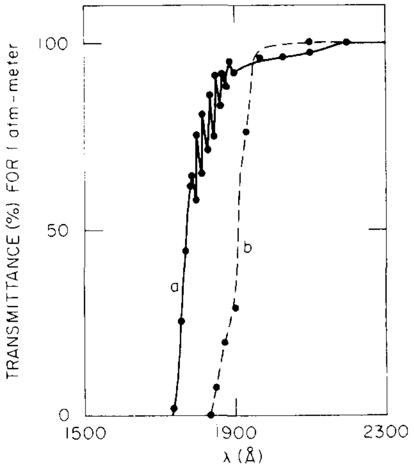

Fig. 4. Curve a: transmission of 1 atm m commercial grade (Allied Chemicals) SF_6. Curve b: transmission of 1 atm m instrument grade (Matheson) SF_6.

following way: The maximum of the first electronic transition was found by Liu et al.6) to be at 1054 Å with the width of 9000 cm^{-1}. We define the absorption edge above as the position shifted from the maximum towards longer wavelength by three times the width. The quoted purity of Matheson instrument grade SF_6 is 99.99%. We have no explanation as to the unexpected lower transmittance of the Matheson instrument grade gas, since the impurities expected in both of the gases are very similar. The results cannot be explained by some accidental contamination since the measurements of the Matheson gas were performed on different gas samples taken from two new lecture bottle containers (obtained on different purchase orders) and were found to be identical.

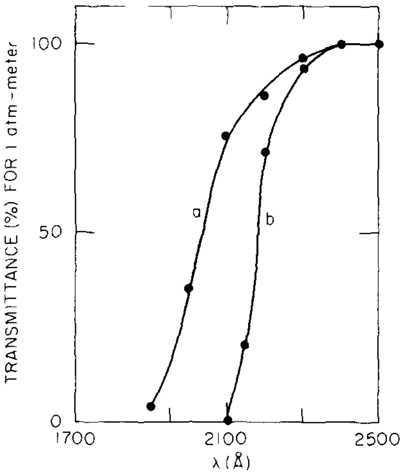

Fig. 5. Curve a: transmission of 1 atm m DuPont refrigeration grade Freon 22. Curve b: transmission of 1 atm m methyl chloride (minimal purity 99.5%).

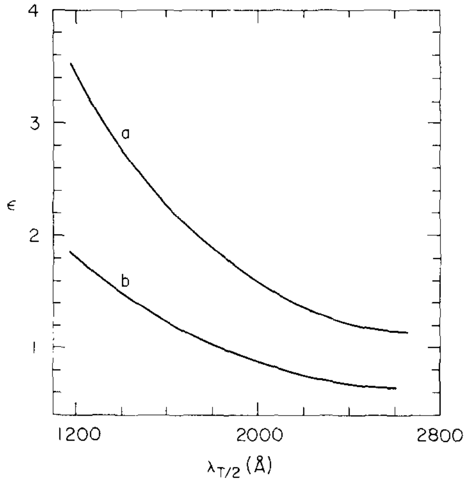

Fig. 6. Calculated ratio, ε, between the output of a phototube coupled to 0.5 mg/cm^2 p-terphenyl and a phototube without shifter, vs gas optical-cutoff wavelength. Curve (a) compares a DVP tube with shifter to a DUVP (quartz face) tube. Curve (b) compares an AVP tube with shifter to a DUVP tube.

Fig. 5 gives the transmission properties of Freon 22 (Du Pont refrigeration grade) and methyl chloride (Matheson 99.5% minimal purity). As mentioned in the experimental section, the absorption of these gases was measured in a high-pressure ultraviolet cell. Since the pressure was well above atmospheric, deviation from an ideal gas approximation was checked by verifying the Beer–Lambert law at different gas pressures. In the measured pressure range (methyl chloride up to 30 psig, Freon 22 up to 134 psig), the measured deviations did not exceed the experimental errors.

In fig. 6 the ordinate, ε, is the ratio between the calculated output of a phototube optically coupled to a layer of 0.5 mg/cm^2 p-terphenyl and the calculated output of a photomultiplier without wavelength shifter.

Fig. 6 represents the dependence of ε on $\lambda_{T/2}$, where $\lambda_{T/2}$ is the wavelength corresponding to 50% optical transmission at a pressure of 1 atm and optical path length of 1 m. The calculations were performed assuming that both tubes (with equal electron-multiplier gain) view the same Cherenkov source, and that their photocathode properties (spectral shape and peak quantum yield) are given by the representative values in the Amperex Data Handbook15). Trivial calculation from the manufacturer's (Amperex) measured value of monochromatic photocathode response at 4370 Å, supplied with each tube, may be used to apply fig. 6 to

TABLE 1

Indices of refraction (at 1 atm pressure and a temperature of 0 °C), wavelengths at 50% transmission (at 1 atm pressure and 1 m optical path length) and equilibrium pressures at 21 °C (for those gases which are liquids at room temperature).

Gas	$\eta = n - 1$	$\lambda_{T/2}$	P_{eq}(psig)
Methane	4.41×10^{-4} 7)	1500 Å	–
Ethane	7.06×10^{-4} 7)	2040 Å	543 8)
Propane	10.05×10^{-4} 7)	1880 Å	109 8)
Butane	14.81×10^{-4} 1)	2230 Å	16.3 8)
Isobutane	14.81×10^{-4} 1)	1820 Å	31 8)
SF_6	7.85×10^{-4} 9)	1770 Å 10)	320 8)
N_2	2.97×10^{-4} 7)	1480 Å 11)	–
Freon 14	4.61×10^{-4} 12)	1760 Å	–
Freon 22	8×10^{-4} 13)	2040 Å	123 8)
Methyl chloride	16.7×10^{-4}	2180 Å	59 8)

any particular tube(s) of the types shown there. The upper curve (a) is the ratio of the output of a DVP tube coupled to 0.5 mg/cm^2 p-terphenyl, to the output of a DUVP (quartz face) tube alone. It is clear that for all cutoff wavelengths, the shifter improves performance, already by a factor of 2 at 1750 Å. The lower curve (b) compares an AVP tube coupled to 0.5 mg/cm^2 p-terphenyl to a DUVP tube. Here it is seen that the shifter makes the two arrangements equivalent for a gas with $\lambda_{T/2} = 1800$ Å. Of course, the DUVP is much more expensive than the DVP, or the even more economical AVP.

Table 1 lists the indices of refraction at 0°C and 1 atm of the various gases mentioned in this report, together with the wavelengths corresponding to 50% transmission at a pressure of 1 atm and optical path length of 1 m. The last column in table 1 lists the equilibrium pressure at 21°C of those gases which are liquids at room temperature.

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10) The listed value is taken from the commercial grade absorption data.

11) Because of the complexity of N_2 absorption spectrum, the wavelength corresponding to the first 50% transmission point is quoted in the table.

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13) Calculated from the given value in ref. 14.

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15) *Amperex data handbook, electron tubes*, part 6 (Amperex Electronic Corporation, Providence, R. I., June 1971). The photocathode spectral responses for the DUVP, DVP, and AVP cathodes are given by fig. 8 (p. 20), fig. 7 (p. 19) and fig. 1 (p. 14), respectively. The peak quantum yields are obtained from fig. 8 (p. 20). The short wavelength edge of the curve labeled "A-Type" on fig. 8 (p. 20) is incorrectly represented there.