

Using $D(O_2)$ and thermochemical data,^{3a} we then have 5.25 volts as the best value for $D(NO)$.

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Properties of Evaporated Films of Aluminum over Chromium

Following the proposal by the author¹ that large astronomical mirrors be coated with metallic films by the evaporation process, considerable work has been done toward the development of the most suitable films for this use.^{2, 3, 4} In coating the Crossley 36 inch reflector of the Lick Observatory,⁴ aluminum was considered to be the best coating for astronomical purposes, for although its hardness is not great, it has excellent tenacity, untarnishability and reflectivity.

A film has been developed in this laboratory which greatly excels pure aluminum in the first of the above properties, and is comparable to it in the remaining three. The glass is first prepared by careful chemical cleaning, and is then bombarded with ions⁵ in the vacuum chamber. A thin film of pure chromium is first evaporated upon the glass, and this is immediately covered by an aluminum film sufficient to make the two films opaque. A method of dissolving chromium placed directly upon glass has been found, and hence such films can be removed, if desired, without injury to the glass surface.

When first deposited this chromium-aluminum film can be scratched fairly easily, but it is hardened instantly by washing in water, alcohol, or even by condensed breath-moisture. The resulting hardness is astonishing; rubbing with a blunt steel instrument, or even with steel-wool affects the film only slightly. A test for resistance to abrasion was made by rubbing a small area of the film 500 times with cheesecloth and with wadded cotton as hard as the hand could rub. A slight increase in scattered light was noticed, but no appreciable decrease in reflectivity could be observed. It was also found that pure aluminum films are considerably harder after washing with water, but even after the water treatment, they are not as hard as the unwashed chromium-aluminum films. A hardened pure aluminum film which had satisfactorily withstood the "adhesive-tape test"⁴ was completely removed from the glass after 50 hard rubs with cheesecloth or with wadded cotton. A chromium-aluminum sample was coated with a layer of kerosene soot onto which was dropped sand and grit, and the mirror was then cleaned with alcohol and water. This was repeated twenty times, with the result that only the faintest surface scratches could be detected. The same test with a hardened pure aluminum film showed a comparable scratching of the surface at the end of four times. These tests were performed upon Corning borosilicate glass.

The tenacity of the chromium-aluminum film is such that nothing has yet been found that will strip it from the glass, although several kinds of tape and glue have been tried.

The aluminum layer can be removed with KOH without removing the underlying chromium. Immersion for a few hours in a concentrated salt solution will likewise remove and dissolve the aluminum. Two samples have been immersed in water and in ethyl alcohol for 10 days without any deterioration of the film. This means that in laboratory use repeated cleaning with alcohol and water can be safely undertaken. Fumes of burning sulphur, of H_2S and of H_2O_2 have no apparent effect upon the films.

The reflectivity of both washed and unwashed films of chromium-aluminum has been measured from $\lambda 6000$ to $\lambda 2900$, and although it varies slightly among samples, it is as good as that reported by Williams and Sabine³ for pure aluminum; *viz.*, 90 percent at $\lambda 6000$ to 80 percent at $\lambda 3000$, and very slightly less than that reported by Pettit.⁶ The aluminum layer is sufficiently thick to act as the sole reflector, and hence might be expected to reflect as well as pure aluminum.

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¹ Williams, Phys. Rev. **41**, 255 (1932).

² Edwards, Phys. Rev. **43**, 205 (1933).

³ Williams and Sabine, Astrophys. J. **77**, 316 (1933).

⁴ Strong, Pub. Ast. Soc. Pac. **46**, 18 (1934).

⁵ This well-known "clean-up" process for metals has been successfully employed by Strong in cleaning glass.

⁶ Pettit, Pub. Ast. Soc. Pac. **46**, 27 (1934).

A Partial Interpretation of the Raman and Infrared Spectra of Benzene

By using the formulas for the normal frequencies of vibration recently published¹ I have been able to assign the Raman-active and infrared-active fundamentals of benzene to definite modes of vibration of the regular plane hexagon model for this molecule. In addition I have found what seems to be a clear-cut case of quantum-mechanical resonance between a fundamental and a combination level.

The selection of the lines to be ascribed to fundamentals has been discussed by others and the choice which I have made was in part based on these previous investigations. There should be seven Raman-active fundamentals and four infrared-active fundamentals, with the nine remaining fundamentals completely inactive. There are four bands in the fundamental region of the infrared which nearly all observers have estimated to be considerably stronger than the other bands. I have chosen these, which lie near 660, 1040, 1480 and 3080 cm^{-1} , as fundamentals. The ten strongest lines in the Raman spectrum, as observed by nearly all investigators, are at 605, 849, 991, 1178, 1584, 1605, 2947, 3047, 3060 and 3184 cm^{-1} . The lines at 991 and 3060 cm^{-1} have been previously ascribed to the symmetrical expansions of the molecule (ν_1 and ν_2 of Fig. 3, reference 1). The other nine active fundamental frequencies are functions of only three force constants besides those determined from ν_1 and ν_2 . I therefore tried varying these three force constants until the calculated frequencies

¹ E. Bright Wilson, Jr., Phys. Rev. **45**, 706 (1934).

agreed most closely with the observed lines. It was possible in this way to get sufficiently close agreement to enable each of the fundamentals to be assigned to one of the theoretical modes of vibration discussed in reference 1. Table I gives this assignment.

TABLE I. *Assignment of fundamental frequencies.*

Raman active		Infrared active
$\nu_1 = 991 \text{ cm}^{-1}$	$\nu_7 = 3047$	$\nu_{11} = 1040 \text{ cm}^{-1}$
$\nu_2 = 3060$	$\nu_8 = (1584-1605)$	$\nu_{18} = 660$
$\nu_6 = 605$	$\nu_9 = 849$	$\nu_{19} = 1480$
	$\nu_{10} = 1178$	$\nu_{20} = 3080$

This assignment is also in accord with the observed polarization of the Raman lines. The remaining lines and bands, which are nearly all much weaker than those assigned to fundamentals in Table I, are to be considered as overtones and combinations from this viewpoint.

I believe that the doublet at 1600 cm^{-1} in the Raman spectrum is to be explained on the basis of quantum-mechanical resonance between ν_8 and $\nu_1 + \nu_6$. The latter sum falls at 1596 cm^{-1} , which is between the members of the doublet. Furthermore, the symmetry of these two levels is the same, so that resonance between them is not forbidden for symmetry reasons. If such resonance occurred two moderately strong lines should occur, as observed, instead of one strong fundamental and one weak combina-

tion frequency. Further evidence for this explanation is provided by the Raman spectra of benzene derivatives. In nearly all of these a single line occurs near 1600 cm^{-1} ; in none of them is a doublet reported. This is in harmony with the fact that the accidental degeneracy $\nu_1 + \nu_6 \sim \nu_8$ is not nearly so close as in benzene.

The suggestion which has several times been made that the spectra of benzene are not compatible with hexagonal symmetry does not appear to be justified since it is based on the supposed coincidence of certain Raman lines with certain infrared bands which I do not believe have been measured with sufficient precision to establish a result so contrary to all the other evidence.

This work is being continued in order to obtain the values of the force constants which give the best fit with experiment, so that a reasonably accurate estimation of the inactive fundamental frequencies may be made, from which it should be possible to make assignments for the other lines and bands as combinations and overtones. Such an assignment would strengthen the provisional interpretation of the fundamentals given here.

I wish to express my appreciation for the criticism and suggestions which I have received from Professors Richard Badger and Linus Pauling in connection with this paper.

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