Inhibition of Diffusion Flames by Methyl Bromide and Trifluoromethyl Bromide Applied to the Fuel and Oxygen Sides of the Reaction Zone

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The difference in extinguishing effectiveness of an inhibitor introduced on the two sides of the reaction zone of diffusion flames has been measured as a function of oxygen concentration in the O_2 - N_2 mixture supplied to the flames. Six fuels and two inhibitors were used. It was found that when the inhibitor was added to the fuel, the volume percentage required for extinguishment was much greater than when added to the oxygen side of the reaction zone, with the single exception of CO flames inhibited by trifluoromethyl bromide. In all cases except the latter, the amount required for extinction increased with increase of the oxygen concentration, being relatively less dependent on oxygen concentration above a certain threshold in the neighborhood of 21 percent when the inhibitor was added to the fuel. Above oxygen concentrations on the order of 25 percent, methyl bromide was completely ineffective when added to the oxygen side of the reaction zone, and above about 32 percent oxygen it was ineffective when added to the fuel, since at this oxygen concentration it burns without additional fuel.

1. Introduction

It was noted, in the course of some preliminary work on the inhibition of propane diffusion flames by methyl bromide, that extinguishment was more readily achieved when the inhibitor was supplied to the air side of the reaction zone than when added to the fuel. A search of the literature revealed that Simmons and Wolfhard $[1]^{1}$ had reported this effect in a paper devoted primarily to the spectroscopy of diffusion flames. Because of the possibility, suggested by this observation, that the inhibitor interferes with some reaction involving oxygen or oxygenated intermediates, it was decided to study the effect as a function of the oxygen concentration in the oxygen-nitrogen mixture supplied to the flame. In addition, it seemed desirable to inhibit the flames with nitrogen added to the fuel so that a datum could be established for estimating the relative efficiencies of the other inhibitors under similar conditions.

2. Apparatus and Procedures

No attempt was made to obtain gases of exceptionally high purity, since the study was aimed primarily toward obtaining information about the differences between the fuel and oxygen sides of diffusion flames. The hydrogen used was prepared commercially by electrolysis and contained ² not more than 0.2 percent impurity which consisted almost entirely of oxygen and nitrogen. Mass spectrometer analysis of the natural gas used indicated that it consisted of 95.15 percent methane, 2.84 percent ethane, 0.63 percent propane, 0.62 percent CO_2 , 0.42 percent N_2 , and a number of heavier hydrocarbons totaling 0.34 percent. The following gases were of commercial purity, the percentage of the major component being specified with no indication of the nature of the minor components: ethane 95 percent, propane 99.5 percent, butane 99.5 percent, carbon monoxide 99.5 percent, methyl bromide 99.4 percent, trifluoromethyl bromide 94.0 percent.

A sketch of the burner is shown in figure 1. The diffusion flame burned on the end of a Pyrex glass tube 7 mm o.d. with 0.8 mm wall thickness. The burner jacket was of 5 cm i.d. and had 18 cm height above the glass beads used to distribute the air flow. The height of the jacket was approximately 15 cm above the burner tube. Flow rates of the various gases were metered through calibrated flow meters. Flows of secondary air in the jacket were maintained high enough so that concentration changes caused by the flames were restricted to the immediate vicinity of the flame and back diffusion of room air into the top of the jacket was avoided.

Extinction of a diffusion flame may be effected by a number of factors, among them being the rate at which the fuel is supplied to the burner and the velocity of the secondary air past the flame. The latter effect was found to be relatively unimportant except at rather low or very high flow rates and was ignored. However, when the rate of fuel supply was too low, for a given burner size, the flame would not burn, and conversely, when the rate was too high, lifting occurred and the flame tended to float off and be extinguished. Between these two extremes, an optimum rate of fuel supply was determined for each of the fuels and for each of the halogenated inhibitors. A typical extinguishment curve is shown in figure 2 (the extinction region lies above the line in each curve). It can be seen that considerable deviation

¹ Figures in brackets indicate the literature references at the end of this proper. ² Analyses furnished by the supplier.

from the optimum value of 220 cm^3 per minute (16 cm/sec lineal velocity) for ethane was permissible with this burner when the inhibitor was added to the fuel and the effect was very small when the inhibitor was added to the air supplied to the flame. Optimum rates for the other gases ranged between 100 and 360 cm³/min.

In general, a set of conditions was established and inhibitor added slowly, either to the fuel or to the mixture supplied to the oxygen side of the flame, until the flame was extinguished. Under some conditions, the flame lifted and floated as much as 10 to 15 cm above the burner where it seemed to be quite stable and would return to the burner if the concentration of inhibitor was reduced. When this occurred, a very large amount of inhibitor was required to accomplish the extinguishment. Under these conditions, the flame was called extinguished at the inhibitor concentration which caused it to suddenly pull away from the burner and rise 1 to 2 cm^{*}above it.





It was felt that, in cases of very high lifting, a certain amount of oxygen was mixing with the gas as primary oxygen and the flame was no longer a true diffusion flame.

3. Results

The results are presented in the form of curves which define the boundary between burning and extinguishment conditions. Figures 3 to 8 inclusive show these regions when the inhibitor was added to the oxygen side of the reaction zone. Burning regions are to the right and below the curves while extin-



FIGURE 2. Extinction characteristics of trifluoromethyl bromide when added to ethane and when added to the air supplied to the ethane diffusion flame, as a function of the fuel rate.





Flames burn in areas to the right of each curve and are extinguished to the left.

guishment results for conditions represented to the left and above the curves. Dotted lines represent the decrease in oxygen concentration produced by dilution of air by the inhibitor. It was impossible to obtain curves similar to those of figure 2 for hydrogen. The reason for this is shown in figure 3, which indicates that this dilution effect was important in the extinguishment of hydrogen flames in air. If the oxygen concentration had been maintained at a constant 20.94 percent independent of the addition of inhibitor, neither of the agents would have been able to extinguish the flames.

The curves of figures 9 to 14, inclusive, show the results of adding methyl bromide, trifluoromethyl bromide or nitrogen to the fuels. As before, the curves are boundaries between regions in which diffusion flames burn or are extinguished, burning taking place under conditions represented to the right and below the curves with extinction above and to the left.

No curve is shown for the effect of CF_3Br added to CO as fuel. The amount required for extinguishment was too small to be measured with the apparatus available. It was estimated, however, to be approximately 1 percent by volume of the fuel rate. It thus appears that the CO diffusion flame was extinguished by a very small amount of CF_3Br regardless of whether it was added from the oxygen or from the fuel side of the reaction zone. There seemed to be no dependence of extinguishment on the oxygen concentration outside the reaction zone, regardless of whether the inhibitor was added to the fuel or oxygen side of it.



FIGURE 4. Extinction of natural gas diffusion flames by CF_3Br (\Box) and CH_3Br (\bigcirc) when the inhibitor is added to the air supplied to the flame.

Flames burn in areas to the right of each curve and are extinguished to the left.



FIGURE 5. Extinction of ethane diffusion flames by CF_3Br (\Box) and CH_3Br (\bigcirc) when the inhibitor is added to the air supplied to the flame.

Flames burn in areas to the right of each curve and are extinguished to the left.



FIGURE 6. Extinction of propane diffusion flames by CF_3Br (\Box) and CH_3Br (\bigcirc) when the inhibitor is added to the air supplied to the flame.

Flames burn in areas to the right of each curve and are extinguished to the left.



FIGURE 7. Extinction of butane diffusion flames by CF_3Br (\Box) and CH_3Br (\bigcirc) when the inhibitor is added to the air supplied to the flame.

Flames burn in areas to the right of each curve and are extinguished to the left.



FIGURE 8. Extinction of carbon monoxide diffusion flames by CF_3Br (\Box) and CH_3Br (\bigcirc) when the inhibitor is added to the air supplied to the flame.

Flames burn to the right of the CH_3Br curve and below the CF_3Br curve and are extinguished to the left of the CH_3Br curve and above the CF_3Br curve.



FIGURE 9. Extinction of hydrogen diffusion flames by nitrogen (\triangle) , CF₃Br (\square) and CH₃Br (\bigcirc) when the inhibitor is added to the fuel.



FIGURE 10. Extinction of natural gas diffusion flames by nitrogen (\triangle) , CF₃Br (\square) and CH₃Br (\bigcirc) when the inhibitor is added to the fuel.



the fuel.



FIGURE 12. Extinction of propane diffusion flames by nitrogen (\triangle) , CF₃Br (\square) and CH₃Br (\bigcirc) when the inhibitor is added to the fuel.









4. Discussion

Relative efficiencies of the three inhibitors for various concentrations of oxygen in the atmosphere supplied to the flame may be derived from the curves (fig. 9 to 14, inclusive) for the case where the inhibitor was added to the fuel. However, when the inhibitor was added to the atmosphere surrounding the flame, allowance had to be made for the reduction in oxygen concentration caused by the addition of inhibitor to the starting mixture of oxygen and nitrogen. Lines parallel to the dotted lines for air in figures 3 to 8, inclusive, give the oxygen con-Values for the percent inhibitor at centration. extinction when normal air was the starting mixture were read from the curves at points where they crossed the dotted lines and are shown in table 1. Also shown in the table are the efficiencies of the two balogenated inhibitors compared to that of nitrogen. It is evident from the table and curves that, in spite of its inertness, the inhibiting effect of nitrogen is different on opposite sides of the reaction zone. Because of this fact, it was felt that nitrogen provided the best basis for a comparison of the efficiencies of the halogenated compounds when applied to the two sides of the reaction zone. The reaction zone of a diffusion flame may be considered as being bounded on one side by the rich combustible limit and on the other by the lean combustible limit, with the stoichiometric mixture somewhere in between, the whole flame being somewhat diluted by products of combustion and the inerts which accompany the reactants. The results of this study indicate that diffusion flames are peculiar in that the amount of nitrogen they will tolerate is dependent upon whether it appears at the lean or rich boundary. For example the hydrogen diffusion flame will not burn if more than 54 percent nitrogen is present in the fuel, even if the oxygen in the O_2-N_2 mixture supplied to the flame is increased to 70 percent (fig. 9). However, if the nitrogen is added with the oxygen, the mixture may contain as much as 94.1 percent nitrogen (fig. 3). In terms of the reaction $H_2+\frac{1}{2}$ $O_2 \rightarrow H_2O$, 6.8 times as much nitrogen may be added with the oxygen as with the fuel. In the absence of chemical effects and neglecting differences in rates of diffusion, it would be expected that the halogenated inhibitors would

behave similarly. The results show that, at 21 percent oxygen in the atmosphere supplied to the flame (where it will tolerate the most inhibitor), CF_3Br gives a value of 0.36 for the ratio of tolerable concentrations on the oxygen and fuel sides of the reaction zone. This value is only 5.4 percent of that for nitrogen, indicating that, while the hydrogen flame behaved similarly toward the addition of nitrogen and CF₃Br on the fuel side, the effects of these additives were quite different when added on the oxygen side. At lower oxygen concentrations these differences were even more pronounced, as they were for some of the hydrocarbon flames. The effect seems to be absent in CO flames; they behaved differently toward the addition of nitrogen, but CF₃Br appeared to differ little in its effect whether added to one side or the other.

Figures 3 and 9 and table 1 show that neither of the halogenated inhibitors was particularly effective in extinguishing a hydrogen diffusion flame, either when added to the air side or to the fuel side of the reaction zone. Their effectiveness increased when used on the oxygen side of hydrocarbon flames, CF_3Br being somewhat more effective than CH_3Br . However, for the CO diffusion flame there was a great difference not only between the effectiveness of the inhibitors, but also between their effects on the CO flame and the flames of the other fuels. The difference between the effectiveness of the two inhibitors for CO flames is, no doubt, connected with the hydrogen contained in the CH_3Br molecule and the well-known effects of hydrogen and hydrogencontaining compounds on the combustion of CO. The decreasing effectiveness of both inhibitors as the amount of free and bound hydrogen in the fuel increased suggests that some reaction of hydrogen opposes the action of the inhibitor.

Figures 3 to 14, inclusive, show that the oxygen concentration in the oxygen-nitrogen mixture supplied to the flame has a rather large effect on the efficiency of the inhibitors, particularly at oxygen concentrations below that found in air. The curves for methyl bromide may be interpreted as showing that the inhibitor starts to become a fuel at about 25 percent oxygen concentration and will burn unsupported as a diffusion flame when the oxygen concentration reaches about 32 percent. This result is not unexpected since Marsh [2] gives lower and upper limits of 14 and 19 percent for upward propa-

TABLE 1. Comparison of extinguishment characteristics of N_2 , CH_3Br , and CF_3Br for various fuels burning in air

	Percentage of inhibitor in air or fuel at extinction							Efficiency relative to nitrogen			
Fuel	When added to air			When added to fuel			Added to air		Added to fuel		
	\mathbf{N}_2	$\mathrm{CH}_3\mathrm{Br}$	CF ₃ Br	\mathbf{N}_2	CH3Br	CF_3Br	${ m CH_3Br}$	CF_3Br	CH₃Br	$\mathbf{CF}_{3}\mathbf{Br}$	
$\begin{array}{c} {\rm H}_{2}.\\ {\rm C}_{1}{\rm H}_{4}.\\ {\rm C}_{2}{\rm H}_{6}.\\ {\rm C}_{3}{\rm H}_{8}.\\ {\rm C}_{4}{\rm H}_{10}.\\ {\rm C}_{0}.\end{array}$	$94.\ 1\\83.\ 1\\85.\ 6\\83.\ 7\\83.\ 7\\90$	$11.7 \\ 2.5 \\ 4.0 \\ 3.1 \\ 2.8 \\ 7.2$	$17.7 \\ 1.5 \\ 3.0 \\ 2.7 \\ 2.4 \\ 0.8$	52. 451. 057. 358. 356. 842. 8	$58.1 \\ 28.1 \\ 36.6 \\ 34.0 \\ 40.0 \\ 19.9$	52. 6 22. 9 35. 1 37. 6 37. 9	$\begin{array}{c} 8.\ 0\\ 33.\ 2\\ 21.\ 4\\ 27.\ 0\\ 29.\ 9\\ 12.\ 5\end{array}$	5.3 55.4 28.5 31.0 34.9 112	$\begin{array}{c} 0.\ 9\\ 1.\ 8\\ 1.\ 6\\ 1.\ 7\\ 1.\ 4\\ 2.\ 2\end{array}$	$1. 0 \\ 2. 2 \\ 1. 6 \\ 1. 6 \\ 1. 5$	

gation in a 2-in. diameter tube when methyl bromide is mixed with oxygen. Figures 3 to 8, inclusive, show that methyl bromide is not effective as an inhibitor when supplied with an oxygen-nitrogen mixture containing more than 25 percent oxygen. This may be interpreted as evidence that combustion products of methyl bromide are ineffective as inhibitors when added on the oxygen side of the diffusion flame. Trifluoromethyl bromide seems to retain its effectiveness to considerably higher oxygen concentrations. When added to the fuel the inhibitors are most effective at oxygen concentrations below that found in air, but do not approach the corresponding efficiencies for the oxygen side of the reaction zone until the oxygen concentration approaches the minimum required to support the uninhibited flame.

The very low efficiency of the halogenated inhibitors when added to the fuel can probably be attributed to failure of the molecules to survive the combined effects of the reducing atmosphere and pyrolysis to which they are subjected as they enter the reaction zone. The results of this study suggest that there is less chance of survival when the inhibitor is added to the fuel than when added to the oxygen side of the reaction zone.

The lack of effectiveness of the decomposition products of CH_3Br and CF_3Br suggest that inhibition may be a result of some reaction or property of the intact inhibitor molecule, or of its freshly released decomposition products. The former concept is not consistent with the theory of Rosser [3] which postulates interference by halogen atoms with chain reactions involving hydrogen atoms. It seems likely that the inhibition reaction takes place in some particular region of the reaction zone, which requires that the inhibitor be stable enough to reach the area where its reaction takes place, but not so stable that it cannot react after it gets there.

 TABLE 2.
 Qualitative parallelism between extinguishing efficiency and dissociative resonance capture of electrons

Compound	Concentra- tion for extinguish- ment at peak flam- mability	Electron attach- ment	Halogen ion formed	Reference
CH ₄ I CBrF ₃ CF ₃ I CH ₃ I CH ₅ F ₂	6. 1 6. 1 6. 8 8. 4	yes yes yes yes	yes yes yes yes	
CH ₃ Br CClF ₂ CClF ₂ CCl4 CClF ₃ CF ₃ CF ₃	$9.7 \\10.8 \\11.5 \\12.3 \\13.4$	yes yes yes yes yes	yes yes yes yes yes	
CCl ₂ F ₂ C ₄ F ₈ SF ₆ HCl CF ₄ CF ₄ CF ₄	$ 14.9 \\ 18.1 \\ 20.5 \\ 25.5 \\ 26.0 $	yes yes yes yes	yes no yes yes	8, 11 9 8 11 5, 8
CH ₃ F C ₈ F ₁₆ O	>8 a	no no yes	no no	

^a Unpublished work from this laboratory.

The present study with halogenated inhibitors and much other unpublished work in this laboratory has brought to our attention the fact that gases known to capture electrons in other systems (mass spectrometer, discharge tubes, ionization detectors for gas chromatographs [4], etc.) have shown strong influences on the combustion processes when they are added to flames. These gases include oxygen, water vapor, nitrogen dioxide, and halogenated organic compounds. Of the many compounds which show this property, only those which form negative ions having a relatively high electron affinity, such as OH⁻, O⁻ and the negative halogen ions, appear to have important effects. A list of halogenated compounds which are known to capture electrons is given in order of decreasing effectiveness as extinguishers, in table 2 [7]. Compounds in the lower half of the table are rather poor inhibitors and are known to either be strongly bonded or to produce no halogen ions in the mass spectrometer. The parallel between the vield of negative ions [5, 6] by dissociative resonance capture of electrons and the efficiency as a flame inhibitor for a number of these compounds is striking and is under investigation. The resonance dissociative capture of electrons may have something to do with the presence of the red and ultra-violet bromine recombination bands shown in the specta by Simmons and Wolfhard [1].

5. Summary

Methyl bromide and trifluoromethyl bromide are much more effective inhibitors when added to the oxygen side of the reaction zone of hydrogen or hydrocarbon diffusion flames than when added to the fuel side. In general, methyl bromide is less effective than trifluoromethyl bromide except at oxygen concentrations below that of air and when added to the fuel. Methyl bromide burns as a diffusion flame, unsupported by additional fuel, at oxygen concentrations above 33 percent. When added to the oxygen side of the reaction zone, it appears to burn as a premixed flame outside the main reaction zone at oxygen concentration above about 25 percent.

For the fuels studied, the difficulty of inhibition increases with the amount of hydrogen in the fuel, when the inhibitor is added to the oxygen side of the reaction zone, but shows no such effect when it is added to the fuel.

The effectiveness of the inhibitors when added to the oxygen side of the reaction zone is a function of the oxygen concentration, methyl bromide being completely ineffective above about 25 percent oxygen, trifluoromethyl bromide retaining some of its effectiveness at much higher oxygen concentrations except for the case of hydrogen as the fuel.

The results have practical application in that they show that the inhibitors are more effective under conditions of low oxygen concentrations and when mixed with the air supplied to a fire.

6. References

- [1] Simmons, R. F. and M. G., Wolfhard, Trans Faraday
- Soc., 52, 53-9 (1956).
 Marsh, D. F., Univ. Calif. publications in pharmacology 1, 32-39 (1940).
- [3] Rosser, W. A., H. Wise, and J. Miller, Seventh Symposium (International) on Combustion, p. 175–82, (But-terworth's (London) 1959).
- [4] Lovelock, J. E., Anal. Chem. 33 162–178 (1961).
 [5] Dibeler, V. H., R. M. Reese, and F. L. Mohler, J. Research NBS 57, 113 (1956) RP2700. [6] Dibeler, V. H. and R. M. Reese, J. Research NBS 54.
- 127 (1955) RP2573.
- [7] Final report on fire extinguishing agents for the period Sept 1, 1947 to June 30, 1950, covering research con-

ducted by Purdue Research Foundation and Dept. of Chemistry under contract M44–009 eng-507 with Army Engrs. Res. and Dev. Labs., Fort Belvoir, Va. Also contained in Engrs. Res. and Dev. Labs. Report 1177, Interim report on vaporizing fire extinguishing

- agents, by J. E. Malcolm. [8] Hickam, W. M. and D. Berg, J. Chem. Phys. **29**, 517–23 (1958).
- [9] Reese, R. M., V. H. Dibeler, and F. L., Mohler, J. Research NBS 57, 367 (1956) RP2725.
 [10] von Hoene, J. and W. M. Hickam, J. Chem. Phys. 32,
- [10] Volt Holley, J. and W. H. Hickan, J. Chem. Phys. 55, 876-9 (1960).
 [11] Buchel'nikova, I.S., J. Exptl. Theoret. Phys. (USSR) 35, 783 (1959).

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Publications of the National Bureau of Standards*

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Selected Abstracts

Truncations in the method of intermediate problems for lower bounds to eigenvalues, N. W. Bazley and D. W. Fox, J. Research NBS 65B, 105 (Math. and Math. Phys.), No. 2, (June 1961).

Two new procedures are developed for determining lower bounds to the eigenvalues of linear operators. The methods are based on the theory of semi-bounded self-adjoint operators in separable Hilbert space. Computation of the lower bounds is reduced to the solution of a matrix eigenvalue problem. The procedures have immediate application in the estimation of eigenvalues and eigenvectors of differential operators occurring in quantum mechanics.

Some boundary value problems involving plasma media J. R. Wait, J. Research NBS 65B, (Math. and Math. Phys.). No. 2, 137 (June 1961).

A plasma, consisting of a neutral mixture of electrons, ions and molecules, in the presence of a constant magnetic field H_0 , possesses a dielectric constant which is in the form of a tensor. Exact solutions of boundary value problems involving such media are obtained for two-dimensional configurations. Explicit results are given for the reflection coefficients of stratified plasma in planar and cylindrical geometry.

The electrically short antenna as a probe for measuring free electron densities and collision frequencies in an ionized region, R. W. P. King, C. W. Harrison, Jr., and D. H. Denton, Jr., J. Research NBS 65D, (Radio Propagation), No. 4, 371 (July 1961).

If the admittance of a missile, satellite, or drone-aircraft antenna is monitored as the vehicle traverses an ionized region. it is possible to determine the free electron density and the collision frequency of the region if theoretical relations between these quantities are available. In this paper formulas are developed that relate the admittance of an electrically short center-driven dipole or a base-driven monopole when immersed in a conducting dielectric to the effective dielectric constant and conductivity of the medium. From wellknown formulas relating these quantities to the free electron density and the collision frequency of an ionized region, these latter may be determined directly from measured admittances. The results obtained when the antenna is treated as a lumped capacitor are considered. It is shown that when the conductivity of the medium is increased to a value that is still quite small, the effect of radiation on the input admit-tance becomes negligible. The electrically short antenna immersed in sea water is discussed briefly.

Low even configurations in the first spectrum of thorium (Th 1), R. E. Trees, *Physica* **26**, 353–360 (1960).

Positions of 21 observed levels in the $6d^2 7s^2$ and $6d^3 7s$ configurations of Th I are calculated with a mean error of ± 143 cm⁻¹, by use of 7 adjustable parameters. This mean error is reduced to ± 47 cm⁻¹ by use of the L(L+1) correction in a calculation with 11 adjustable parameters. The agreement between observed and calculated g-values is satisfactory. The parameters are compared with ones already published for/related configurations in the spectra of Th II and Th III. With one exception, similarly defined parameters show a roughly linear variation with the degree of ionization, in accordance with simple expectation. The effect of neglecting the $6d^4$ configuration in Th I is briefly discussed to explain this exception. High-dispersion spectra of jupiter, C. C. Kiess, C. H. Corliss, and H. K. Kiess, Astrophys. J. 132, No. 1, 221–231 (July 1960).

In May 1957 the spectrum of Jupiter was photographed with concave gratings of high dispersion at the Slope Observatory on Mauna Loa. The spectrograms covered the region from 3,600 to 8,900 A. Tables are presented listing the wavelengths and estimated intensities of lines that make up the structures of the ammonia bands at 6,450 and 7,900 A, and of the methane bands at 6,200, 7,250, 8,420, and 8,620 A. In the infrared four lines of the (3.0) band in the quadrupole rotation-vibration spectrum of H₂ were measured. In the violet and ultra-violet regions of the planet's spectrum a continuous absorption was recorded that closely resembles the continuous absorption of the nitrogen tetroxide molecule.

A prototype rubidium vapor frequency standard, R. J. Carpenter, E. C. Beaty, P. L. Bender, S. Saito, and R. O. Stone, *IRE Trans. Instrumentation* **1–9**, *No.* 2 (Sept. 1960).

A prototype rubidium vapor frequency standard has been developed for possible use in a satellite measurement of the gravitational frequency shift predicted by the Theory of Relativity. The relative transition frequencies of several optically pumped rubidium vapor absorption cells have been shown to remain stable to one part in 10^{11} or better for a period of one month. A crystal controlled oscillator is corrected to a subharmonic of the rubidium transition frequency by a fully electronic servo system. The standard is transistorized, small in size, low in weight, and requires less than 10 watts to operate.

Application of the method of polarized orbitals to the scattering of electrons from hydrogen, A. Temkin and J. C. Lamkin, *Phys. Rev.* **121**, *No. 3*, 788–794 (*Feb. 1961*).

Phys. Rev. 121, No. 3, 788–794 (Feb. 1961). The s-, p-, and d-wave scattering of slow electrons from atomic hydrogen is calculated by the method of polarized orbitals. Utilization of a transformation of Omidvar avoids the iterative procedure of solving the associated integrodifferential equations. The s-wave scattering is smaller than that given by the exchange approximation, and the scattering lengths are within the upper bounds found by Rosenberg, Spruch, and O'Malley. The d-wave phase shifts are too small to explain a resonance in the total cross section. However they are much larger than those of the exchange or Born approximation, and they give considerable structure to the differential cross section curves. The p-wave phase shifts are not much increased by the polarization effects.

Atomic energy levels in crystals, J. L. Prather, NBS Mono. 19 (1961) 60 cents.

Discrete energy levels observed within certain crystals are treated as due to perturbations of the energy levels of the free ion by an electrostatic field arising from the crystal lattice. The analytic procedures for determining the field from the charge configuration are given, and the resulting fields are classified according to their symmetry. After a general survey of group-theoretical ideas, the applicable groups are analyzed in detail, and characters appropriate for both integral and half-integral angular momenta of the free ion are tabulated. These are applied to the determination of the number and type of levels arising from a free ion level with $J \leq 8$. The results of this analysis are tabulated, as are the selection rules for electric dipole, magnetic dipole, and electric quadrupole transitions. Calculation of the perturbation matrix elements by the use of Wigner and Racah coefficients is discussed. Examples of the application of these several techniques to specific problems are given.

Spectroscopy of fluorine flames. I. Hydrogen-fluorine flame and the vibration-rotation emission spectrum of HF, D. E. Mann, B. A. Thrush, D. R. Lide, J. J. Ball, and N. Acquista, J. Chem. Phys. **34**, No. 2, 420–431 (Feb. 1961).

The hydrogen fluoride vibration-rotation emission spectrum from a hydrogen-fluorine diffusion flame has been studied under high dispersion from 3,200 cm⁻¹ in the infrared to about 5,500 A in the visible. Measurements were made on the rotational lines in 23 bands including (1–0), (2–1), and (3–2) of the $\Delta v=1$ sequence; (2–0), (3–1), (4–2), (5–3), and (6–4) of $\Delta v=2$; (3–0), (4–1), (5–2), and (6–3) of $\Delta v=3$; (4–0), (5–1), (6–2), (7–3), (8–4), and (9–5) of $\Delta v=4$; and (5–0), (6–1), (7–2), (8–3), and (9–4) of $\Delta v=5$. Complete rotational and vibrational analyses were carried out. The constants B_v D_v , and H_v are given for v=0 to 9. The data were extensive and precise enough to require an extended Dunham treatment from which 18 coefficients could be determined, including those for terms in $(v+1/2)^5$ and J^4 $(J+1)^4$. Band centers for 22 bands and the vibrational term values E for V=0 to 9 are given.

Mean motions in conditionally periodic separable systems, J. P. Vinti, J. Research NBS 65B, (Math. and Math. Phys.), No. 2, 131 (June 1961).

A search of the literature failed to disclose any general statement or proof of a theorem informally current among dynamical astronomers. The present paper gives a proof of the theorem, which states that, in any conditionally-periodic, separable system, the mean frequency n_k of any separation coordinate q_k is equal to $\nu_k \equiv \partial \alpha_1 / \partial J_k$. Here α_1 is the energy and J_k is the k'th action variable. The proof is carried out for nonsingular Staeckel systems, so that it is applicable to any nonpolar orbit of an artificial satellite, when the potential leads to separability.

On the absorption spectrum of CF_2 and its vibrational analysis, D. E. Mann and B. A. Thrush, J. Chem. Phys. **33**, No. 6, 1732-1734 (Dec. 1960).

The flash photolysis of CF_2Br_2 has been used to obtain the absorption spectrum of the CF_2 radical. The principal features of the spectrum are a progression of the upper state bending frequency, and a number of weak bands which are shown to arise from a vibrationally excited lower state. There is no evidence for transitions involving stretching vibrations. The vibrationless origin of the system $(v_1'=0, v_2'=0; v_1''=0, v_2''=0)$ is shown to lie at approximately 37695 cm⁻¹. The deformation frequencies of the lower and upper states are about 660 and 500 cm⁻¹, respectively.

Microwave spectrum of cis-difluoroethylene, V. W. Laurie, J. Chem. Phys. 34, No. 1, (Jan. 1961).

The microwave spectrum of cis-difluoroethylene, HFC=CHF, has been investigated in the region 17–36 kMc. Observed rotational constants (Mc) for the ground vibrational state of $C_2^{12}\text{H}_2\text{F}_2$ are $a_0=21103.31$, $b_0=5930.35$, $c_0=4622.27$; for $C^{13}C^{12}\text{H}_2\text{F}_2$, $a_0=20752.10$, $b_0=5900.17$, $C_0=4586.92$. From these constants a structure is obtained with $r_{ec}=1.324$ A, $r_{CF}=1.337$ A, rCH=1.080 A, $<FCC=122^{\circ}9'$, and <HCC= $121^{\circ}16'$. Rotational constants for $V_5=1$ have also been determined. A dipole moment of 2.42 D is calculated from the Stark effect.

Comparison with previously existing data for ethylene, vinyl fluoride, and vinylidene fluoride shows that there is a shortening of both the CF and the CC bonds with increasing fluorine substitution.

Electron scattering in high magnetic field, A. H. Kahn, *Phys. Rev.* **119**, *No.* 4, 1189–1192 (Aug. 1960).

Electrical conductivity in a strong magnetic field is calculated for the case of scattering by delta-function impurities. The impurity concentration is taken as sufficiently weak that collision broadening may be neglected. The scattering by an individual center is solved exactly rather than by perturbation theory. As a result, transition probabilities for an electron at the bottom of a Landau level vanish, rather than diverge. Expressions are given for the longitudinal and transverse conductivities in the oscillatory range, and in the quantum limit range for degenerate and nondegenerate statistics. The relation of this theory to those employing collision broadening is discussed.

Dielectric constant and dielectric loss of TiO_2 (Rutile) at low frequencies, R. A. Parker and J. H. Wasilik, *Phys. Rev.* **120**, No. 5, 1631–1637 (Dec. 1960).

Measurements have been made of the complex capacitance (C=C'-iC'') of undoped, high resistance, single crystal TiO₂ (rutile) in vacuum at 78, 195, 273, and 300°K as a function of frequency between 10¹ and 3×10^6 cps with a 0.1 volt ac signal. With the field in the c-direction, one low frequency loss peak is found at 200 cps. The capacitance C' and loss C'' of a 2 mm cube with the field in the c-direction are characterized by $\frac{1}{2}\pi\tau=200 \sec^{-1}$, $\tan \delta_{200 \ eps}=0.8$, and a dielectric constant ϵ'_{1Mc} of 170, while $\epsilon'_{20 \ eps}=30,000$. The loss and low frequency capacitance of the crystal are directly proportional to the area of the electrodes and depend but slightly on the sample thickness, electrode materials and surface treatment. C' and C'' have been measured at 300 °K as a function of the oxygen vacancy concentration in the crystal. C' and C'' have also been measured as a function of dc bias from 0 to 400 volts; C'_{20 eps}, C''_{max} and τ are proportional to V^{-n} where n is between 0.3 and 0.8. The results of the experiments can be explained by an electron-deficient barrier layer whose thickness increases with increasing applied voltage. When the dc voltage in the c-direction is changed, effects are observed whose time constants are of the order of hours or even days.

Hydrogen-bonding in calcium-deficient hydroxyapatites, A. S. Posner, J. M. Stutman, and E. R. Lippincott, Nature 188, No. 4749, 486-487 (Nov. 1960).

A quantitative infrared absorption spectrophotometric technique was developed for the analysis of the hydrogen bond content of a series of calcium-deficient hydroxyapatites. Index of refraction and X-ray diffraction techniques and chemical analysis were used to characterize the precipitated calcium phosphates as low-calcium hydroxyapatites. Using a sapphire pressure cell in the infrared spectrophotometer, the 3,400 cm⁻¹ absorption band (i.e., the hydrogen bonded O–H stretching frequency) was used for hydrogen bond analysis in conjunction with a potassium ferricyanide internal standard band at 2,105 cm⁻¹. The absorbance due to hydrogen bonding, obtained from the spectrum by a base line method, was found to be directly proportional to the hydrogen bond content predicted from the low calcium content of the hydroxyapatite samples. To balance the electrical charges due to missing calciums in certain hydroxyapatites an earlier paper suggested hydrogen bonding between oxygen atoms of adjacent orthophosphate groups. The O–O distance of 2.85 A, calculated from the H–O stretching frequency, shows that this is a reasonable assumption for the location of the proton bond.

Amplitude and angular scintillations of the radio source Cygnus-A observed at Boulder, Colorado. R. S. Lawrence, J. L. Jespersen, and R. C. Lamb, J. Research NBS 65D, (Radio Prop.), No. 4, 333 (Aug. 1961).

Variations in the apparent flux and position of the radio source Cygnus-A were recorded at 53 and 108 Mc/s using a two-element, phase-sweeping interferometer located at Boulder, Colorado. An ionospheric sounder operating at Ellsworth, Nebraska, provided, for a few hours each day, simultaneous vertical-incidence measurements on the ionosphere at its intersection with the line of sight from Boulder to the radio star. Amplitude scintillations observed at Boulder over a twelve-month period are compared with ionograms taken at Ellsworth. Positive correlation is found between amplitude scintillations and spread F, while no significant correlation is found with sporadic E.

Detailed analysis of the scintillations indicates that the probability distribution of the amplitude can be represented by the Rice probability distribution function. The zenithangle dependence of the amplitude scintillations does not agree with a theory based upon isotropic ionospheric inhomogeneities. Microtechnique for the infrared study of solids diamonds and sapphires as cell materials, E. R. Lippincott, F. E. Welsh and C. E. Weir, Anal. Chem. 33, 137–143 (Jan. 1961).

Difficulties are sometimes encountered in obtaining the infrared spectra of solids. Accordingly, it is desirable to supplement the available techniques for solids with new procedures which would increase the number and type of solids capable of being studied. A cell which has been used to obtain the infrared spectra of a wide variety of solids in the 2-35 micron region is described. Diamonds and sapphires are used as window materials. The method is essentially a microtechnique. Representative spectra utilizing sample weights as small as 4γ (4×10^{-6g}) have been obtained. The cell can be used in a routine manner to obtain the infrared spectra of corrosive liquids and, as far as is known, of all solids. In addition, the visible and ultraviolet regions can be studied by means of this cell.

On the properties of the vapor pressure curve, E. H. Brown, Cryogenics 1, No. 1, 37-40 (Sept. 1960).

Some general mathematical properties of the vapor pressure as a function of temperature are investigated by rigorous methods. In particular, the limiting shape of the vapor pressure curve is shown to be determined by the vanishing of the limits of the derivatives of all orders in the neighborhood of absolute zero. Some comments on the inapplicability of the Third Law of Thermodynamics to the sublimation curve are included.

Digital methods for the extraction of phase and amplitude information from a modulated signal, R. S. Lawrence, J. L. Jespersen, and R. C. Lamb, J Research, NBS 65D (Radio *Prop.*), *No.* 4, 351 (*Aug.* 1961). A description is given of three digital methods which have been

used to recover amplitude and phase information from a modulated sinusoidal signal sampled at equal intervals of not more than one-sixth of a period. The first method, the 'zero-crossing'' method, is economical of computer time and for modulation which is not too deep and does not contain frequencies near the carrier frequency, accurately recovers the phase and amplitude modulation. The second method, the 'filter' ' method, is more laborious but it gives better accuracy and will operate with deeper and more rapid modulation. The third method, a statistical approach, will work with severely overmodulated signals, but it yields only a statistical summary of the modulation. The methods were designed specifically for analysis of radio-star scintillation records but they may be applied to many other modulated signals.

A spectrophotometric atlas of the spectrum of CH from 3,000 A, to 5,000 A, A. M. Vass and H. P. Broida, NBS Mono. 24 (1961) 20 cents.

The near ultraviolet and visible emission spectrum of CH was recorded and presented in the form of a spectrophoto-The spectrum was recorded photoelectrically metric atlas. from an acetylene-oxygen flame in the region 4,900 to 3,000 Å by use of a high-resolution grating monochromator. Each of the lines in the CH spectrum is identified.

Measurement of reflections and losses of waveguide joints R. W. Beatty, G. F. Engen, and W. J. Anson, *IRE Trans. Instrumentation* 1–9, *No. 2, 219–226* (Sept. 1960). The reflection and loss of a waveguide joint are quantified by its VSWR and efficiency, respectively. These are conveni-

ently and accurately determined by techniques which employ a reflectometer with auxiliary tuners and an adjustable sliding termination. Depending upon the stability and gain of the associated apparatus, measurements of VSWR's of 1.001 and lower, and of efficiencies of 99.99 percent and higher may be obtained. The attenuations of short lengths of waveguide may be determined at the same time that the efficiency measurement is made.

Propagation of electromagnetic waves along a thin plasma sheet, J. R. Wait, Can. J. Phys. 38, 1586-1594 (1960).

It is shown that a thin ionized sheet will support a trapped The effect of a constant and uniform magnetic surface wave. field is to modify the phase velocity and polarization of the surface wave. The essential features are illustrated by numerical results for selected values of the electron density, collision frequency and gyro frequency. The effect of locating the plasma sheet near and parallel to a conducting plane is also considered. In this situation other modes of a wave-guide type are possible in addition to the surface wave.

The sensitivity of photographic film to 3-mey neutrons and to thermal neutrons, M. Ehrlich, Health Phys. 4, 113-128 (1960). Measurements were made to determine the sensitivity to 3-Mev neutrons and to thermal neutrons of three commercial photographic films (DuPont film types 502, 510, and 606). The films were exposed in the conventional "NBS holders", consisting of Bakelite covered with thin layers of lead and tin. The results of the measurements were compared with results obtained by rough theoretical estimates. The sensitivity of the films to neutrons was found to be relatively low. On the least sensitive film, a photographic density of 0.1 was obtained with a fast-neutron exposure of 6.8×10^{10} n/cm². On the most sensitive film, the exposure for the same density was 4.9×10^9 n/cm². The ratios of the films' fast neutron-togamma-ray sensitivities were found to be roughly equal to the reciprocal of the ratios of their average grain diameters. The thermal neutron sensitivity of the films was of the same order as the 3-Mev sensitivity, and was roughly the same for all three film types. In the few cases in which values for the neutron sensitivity could be obtained theoretically, they showed order-of-magnitude agreement with the experimental values.

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- Amplitude and angular scintillations of the radio source Cygnus-A observed at Boulder, Colorado. R. S. Lawrence, J. L. Jespersen, and R. C. Lamb. (See above abstract.)
- Digital methods for the extraction of phase and amplitude information from a modulated signal. R. S. Lawrence, J. L. Jespersen, and R. C. Lamb. (See above abstract.) Comparison between mode theory and ray theory of VLF
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On the theory of mixed-path ground-wave propagation on a spherical earth. J. R. Wait.

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- Units of weight and measure (United States customary and metric) definitions and tables of equivalents, L. V. Judson, NBS Misc. Publ. 233 (1960) 40 cents.
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- Medical X-ray protection up to three million volts, NBS Handb. H76 (1961) 25 cents.
- Precision measurement and calibration, S. F. Booth: Electricity and electronics, NBS Handb. 77, Vol. I (1961) \$6.00; Heat and mechanics, NBS Handb. 77, Vol. II (1961) \$6.75; Optics, metrology, and radiation, NBS Handb. 77, Vol. III (1961) \$7.00.
- Quarterly radio noise data, September, October, November 1960, W. Q. Crichlow, R. T. Disney and M. A. Jenkins, NBS TN18-8 (PB151377-8) (1961) \$1.75.
- Prolonged space-wave fadeouts in tropospheric propagation, Barsis and M. E. Johnson, NBS TN88 (PB161589) (1961) \$2.00.
- Physical metallurgy and mechanical properties of materials: Ductility and the strength of metallic structures, J. Frankland, J. Eng. Mech. Div. Proc. Am. Soc. Civil Eng. 86, No. EM 6, 45-52 (Dec. 1960).
- Cryogenic impurity adsorption from hydrogen, M. J. Hiza, Chem. Engr. Progress 55, No. 10, 68–71 (Oct. 1960)
- Nomenclature for standards of radioactivity, A. G. McNish, Intern. J. Appl. Radiation and Isotopes 8, 145-146 (Jan. 1960)
- Lithium, M. R. Meyerson, Am. Soc. for Metals Handbook 1, 1213(1961).
- Tensile cryostat for the temperature range 4° to 300° Kelvin, R. M. McClintock and K. A. Warren, ASTM Bull. 1, No. 2, 95–98 (Feb. 1961).
- The minima of cyclic sums, K. Goldberg, J. London Math. Soc. 35, 262-264 (1960).
- Normal approximation to the chi-square and non-central F probability functions, N. C. Severo and M. Zelen, Bio-metrika 47, No. 3 & 4, 411-416 (1960).
- Definitions relating to metals and metalworking, M. R. Meyerson and S. J. Rosenberg, Am. Soc. Metals Handb. 1, 1-41 (1961).
- 1, 1-41 (1901).
 Stress-rupture tests at 1350° F on type 304 stainless steel, W. D. Jenkins, W. A. Willard and W. J. Youden, ASTM Bull. 1, No. 2, 104–108 (Feb. 1961).
 Techniques in calorimetry. I. A Noble-metal thermocouple for differential use, E. D. West, Rev. Sci. Inst. 31, No. 8, 2020 002 (4 1000)
- 896-897 (Aug. 1960).
- Paratellurite, a new mineral from Mexico, G. Switzer and H. E. Swanson, Am. Mineralogist 45, 1272 (Nov.-Dec. 1960).
- Evaluation of micrometer and microscopical methods for measuring thickness of floor coverings, E. Horowitz, J. Mandel, R. J. Capott, and T. H. Boone, ASTM Bull. 1, No. 2, 99–102 (Feb. 1961).
- Electrodeposition of metals from nonaqueous media, A. Brenner, Chapter on Electrodeposition, Encyclopedia Chem. Tech. 2d Suppl., 315–324 (Jan. 1961).
- The nature, cause, and effect of porosity of electrodeposits VI. Note on a magnetic method of detecting corrosion currents, F. Ogburn and W. H. Roberts, Plating 48, No. 2, 168–169 (Feb. 1961).
- The height of maximum luminosity in an auroral arc, F. E. Roach, J. G. Moore, E. C. Bruner, Jr., H. Cronin and S. M. Silverman, J. Geophys. Research 64, No. 11, 3575-3580 (Nov. 1960).
- Standards and testing, the key to quality, B. E. Foster, Eng. Bull., Purdue Univ. XLIV, No. 6, 54–62 (Nov. 1960).
 A radio-frequency permittimeter, R. C. Powell and A. L.

Rasmussen, IRE Trans. Instrumentation I-9, No. 2, 179-184 (Sept. 1960)

- Subgroups of the modular group and sums of squares, M. Newman, Am. J. Math. 82, No. 4, 761–778 (Oct. 1960).
- Phase equilibria in the system cadmium oxide-niobium oxide, R. S. Roth, J. Am. Ceram. Soc. 44, No. 1, 49-50 (Jan. 1961).
- Redetermination of the chromium and nickel solvuses in the chromium-nickel system, C. J. Bechtoldt and H. C. Vacher, Trans. Metallurgical Soc., Am. Inst. Mining Engrs. 221, 14–18 (Feb. 1961).
- A modulated subcarrier technique of measuring microwave phase shifts, G. E. Schafer, IRE Trans. Instrumentation **I-9**, No. 2, 217–219 (Sept. 1960).
- An analysis of the accumulated error in a hierarchy of calibrations, E. L. Crow, IRE Trans. Instrumentation I-9, No. 2, 105–114 (Sept. 1960).
- Hydrogen sulfide precipitation of the elements from 0.2-0.5 normal hydrochloric acid, J. I. Hoffman, Chemist Analyst 50, No. 1, 30 (Mar. 1961).
- Generating functions for formal power series in non-commuting variables, K. Goldberg, Proc. Am. Math. Soc. 11, No. 6, 988–991 (Dec. 1960).
- Tests for regression coefficients when errors are correlated. M. M. Siddiqui, Ann. Math. Stat. 31, No. 4, 929-938 (Dec. 1960)
- A recommended standard resistor-noise test system, G. T. Conrad, Jr., N. Newman and A. P. Stansbury, IRE Trans. Component Parts **CP-7**, No. 3, 71–88 (Sept. 1960). A transfer instrument for the intercomparison of microwave
- power meters, G. F. Engen, IRE Trans. Instrumentation **I-9**, No. 2, 202–208 (Sept. 1960).
- Standards and measurements of microwave surface imped-Standards and measurements or incrowave surface impedance, skin depth, conductivity and Q, H. E. Bussey, IRE Trans. Instrumentation I-9, No. 2, 171–175 (Sept. 1960).
 Plating gun bores, V. A. Lamb and J. P. Young, Ordnance XLV, No. 245, 725–727 (Mar.–Apr. 1961).
 Integrated starlight over the sky, F. E. Roach and L. R. Magill, Astrophys. J. 133, No. 1, 228–242 (Jan. 1961).

- Low temperature static seals using clastomers and plastics, D. H. Weitzel, R. F. Robbins, G. R. Bopp, and W. R. Bjorklund, Rev. Sci. Inst. **31**, No. 12, 1350–1351 (Dec. 1960)
- Electrodeposition of metals from nonaqueous media, A. Brenner, Encyclopedia of Chemical Technology, 2d Suppl., 315–324 (Interscience Encyclopedia 1960).
- FM and SSB radiotelephone tests on a VHF ionospheric FM and SSB radiotelephone tests on a VIT fonospheric scatter link during multipath conditions, J. W. Koch, W. B. Harding and R. J. Jansen, IRE Trans. Commun. Systems CS-8, No. 3, 183–186 (Sept. 1960).
 Propagation of error in a chain of standards, A. G. McNish
- and J. M. Cameron, IRE Trans. Instrumentation I-9, No. 2, 101–104 (Sept. 1960).
- Absolute measurement of temperatures of microwave noise sources, A. J. Estin, C. L. Trembath, J. S. Wells, and W. C. Daywitt, IRE Trans. Instrumentation **I-9**, No. 2, 209-213 (Sept. 1960).
- Surface roughness of gold castings, J. J. Barone, R. L. Huff and G. Dickson, Dental Progr. 1, No. 2, 78-84 (Jan. 1961).
- Comparison measurements with intensity standards for high energy bremsstrahlung, J. S. Pruitt and W. Pohlit, Z. Naturforschung **15b**, No. 9, 617–619 (1960).
- Stability of thermoset plastics at high temperatures, S. L.
- Madorsky and S. Straus, Modern Plastics 38, 134-140 (Feb. 1961).
- Immiscibility and the system lanthanum oxide boric-oxide, E. M. Levin, C. R. Robbins and J. L. Waring, J. Am. Ceram. Soc. 44, No. 2, 87–91 (Feb. 1961).
- Absorption and scattering of photons by holmiun and orbium, E. G. Fuller and E. Hayward, Proc. Intern. Conf. Nuclear Structure, 761-766 (Kingston, Canada 1960).

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