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Method of Measuring Emissivities of Metals in the Infrared*

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A method of measuring normal spectral emissivities in the infrared region from 1 to 13 μ is described. It consists of comparing the rate of emission of radiant energy from a blackbody with that from the specimen. The two observed radiances are made equal by adjusting the temperatures. An equation is derived for use in calculating the emissivity for the observed temperatures. The main sources of error arise in the measurement of the temperature of the specimen and the temperature of the blackbody. As an example of the method, the normal spectral emissivity of gold has been measured in the range from 4 to 13 μ at temperatures from 550 to 1,000 °K. The emissivity was found to range from 0.014 at 4 μ and 550 °K to 0.0256 at 9 μ and 1,000 °K. A table is included which lists the values of emissivity from 4 to 13 μ and from 550 to 1,000 °K at intervals of 50 °K.

1. Introduction

The normal spectral emissivity of many metals such as gold, platinum and aluminum is very low in the infrared region from 4 to 13 μ. Some measurements have been carried out at high temperatures in the visible spectrum [1–4],[1] but measurements in the infrared spectrum to 13 μ have not been undertaken. The emissivity of metals in the infrared may be calculated from the reflectivity, R, using the Kirchhoff relationship

$$\epsilon = 1 - R.$$

For this calculation reflectance measurements made at room temperature are available from several sources, but in most cases the reflectance measurements are only good to about ± 1 percent thus giving rise to uncertainties of ± 5 to ± 50 percent for the calculated emissivities of most metals. A noteworthy exception to this is the recent very accurate reflectance measurements made by Bennett and Koehler [5] on aluminum. In addition Harris and Fowler [6] and Lameris [7] have made some very good measurements on gold.

While this paper is primarily concerned with the development of a method for measuring the spectral emissivity of metals, some results are reported on the normal spectral emissivity of gold in the infrared spectrum from 4 to 13 μ. A method of measuring the spectral emissivity of metals will be described in the next section.

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[1] Figures in brackets indicate the literature references at the end of this paper.

2. Experimental Procedure

The experimental arrangement consisted of an infrared spectroradiometer with a sodium chloride prism and thermocouple for measuring the rate of emission of energy in the region from 1 to 13 μ. A double pass optical system was employed so that the stray radiation would be greatly reduced. The spectroradiometer was calibrated for wavelength settings with the absorption bands of polystryene, CO_2 and H_2O. Rather large spectral slit widths were used in this work varying from 0.18 μ at 2 μ to 0.1 μ at 10 μ. However, since neither the blackbody curve nor the emitted-energy curve of the specimen has a very large second derivative with respect to wavelength, the emissivity values which were determined were nearly independent of the slit width used. A blackbody and the specimen to be measured were placed on a platform which could be moved so that the specimen or the blackbody radiated on the entrance slit of the spectrometer. This general type of arrangement has been used in previous work and a more detailed description of the procedure can be found elsewhere [8].

An essentially different method of comparing the radiance from the blackbody and the specimen has been devised. This method consists of adjusting the radiance of both sources (at the same wavelength) to be nearly equal. The effect of nonlinearity of the detector amplifier response is minimized by this procedure. Since the measurements were to be made on metals of low emittance, this required that the blackbody be at a lower temperature than the specimen. In order to reduce the error of ambient change to a minimum, alternate readings were made on the blackbody and specimen during a small time interval.

The emissivity calculations were based upon the following equations. If we define

$N_b(\lambda_b)$ = rate of emission of radiant energy by a blackbody radiator at temperature t_b within the wavelength interval $\lambda \pm d\lambda$ per unit of time, area, and solid angle,

$N_s(\lambda t_s)$ = rate of emission of radiant energy by the specimen at temperature t_s within the wavelength interval $\lambda \pm d\lambda$ per unit of time, area, and solid angle,

$\epsilon_s(\lambda t_s)$ = emissivity of the specimen at temperature t_s for the wavelength interval $\lambda \pm d\lambda$,

t_r = room temperature,

t_s = specimen temperature,

t_b = blackbody temperature,

t_m = monochromator and detector temperature,

$R_b(\lambda t_b)$ = reading of instrument set to view blackbody at temperature t_b,

$R_s(\lambda t_s)$ = reading of instrument set to view specimen at temperature t_s;

then,

$$R_b(\lambda, t_b) = k_1[N_b(\lambda, t_b) - N_b(\lambda, t_m)] \tag{1}$$

and

$$R_s(\lambda, t_s) = k_2\{[N_s(\lambda, t_s) - N_b(\lambda, t_m)] + [1 - \epsilon_s(\lambda, t_s)]\, N_b(\lambda, t_r)\}. \tag{2}$$

Here k_1 and k_2 are proportionality constants and $k_1 = k_2$ in this method.

Also,

$$N_s(\lambda, t_s) + [1 - \epsilon_s(\lambda, t_s)]N_b(\lambda, t_r) = \frac{N_s(\lambda, t_s) - N_b(\lambda, t_m) + [1 - \epsilon_s(\lambda, t_s)]N_b(\lambda, t_r)}{N_b(\lambda, t_b) - N_b(\lambda, t_m)} [N_b(\lambda, t_b) - N_b(\lambda, t_m)] + N_b(\lambda, t_m). \tag{3}$$

By substitution,

$$N_s(\lambda, t_s) = \frac{R_s(\lambda, t_s)}{R_b(\lambda, t_b)} [N_b(\lambda, t_b) - N_b(\lambda, t_m)] + N_b(\lambda, t_m) - [1 - \epsilon_s(\lambda, t_s)]N_b(\lambda, t_r). \tag{4}$$

Let

$$\frac{R_s(\lambda, t_s)}{R_b(\lambda, t_b)} = 1. \tag{5}$$

Then

$$N_s(\lambda, t_s) = N_b(\lambda, t_b) - [1 - \epsilon_s(\lambda, t_s)]N_b(\lambda, t_r). \tag{6}$$

By definition,

$$\epsilon_s(\lambda, t_s) = \frac{N_s(\lambda, t_s)}{N_b(\lambda, t_s)}. \tag{7}$$

From eq (6),

$$\epsilon_s(\lambda, t_s) = \frac{N_b(\lambda, t_b) - [1 - \epsilon_s(\lambda, t_s)]N_b(\lambda, t_r)}{N_b(\lambda, t_s)} \tag{8}$$

or

$$\epsilon_s(\lambda, t_s)N_b(\lambda, t_s) = N_b(\lambda, t_b) - N_b(\lambda, t_r) + \epsilon_s(\lambda, t_s)N_b(\lambda, t_r). \tag{9}$$

Combining terms we obtain,

$$\epsilon_s(\lambda, t_s) = \frac{N_b(\lambda, t_b) - N_b(\lambda, t_r)}{N_b(\lambda, t_s) - N_b(\lambda, t_r)}. \tag{10}$$

The values of $N_b(\lambda, t)$ in eq 10 can be evaluated from tables of blackbody radiation or calculated from the relation.

$$N(\lambda, t) = \frac{C_1}{\lambda^5(e^{C_2/\lambda T} - 1)},$$

where

$C_2 = 1.4380$ cm °K. The constant C_1 cancels out.

3. Discussion of Possible Errors

Since the emissivity of a metal is a quantity intrinsic to the substance one may consider sources of error as divided into two categories: (1) deviation of the sample from the ideal, and (2) experimental errors.

The first type of error may generally be attributed to impurities in the metal sample and/or nonideal surface effects peculiar to the specimen. It is believed that the purity of our specimen was not a source of error. The gold ribbon which has been measured by this method was part of a sample which had been tested by spectral analysis and found of high purity. The specimen surface was mirror smooth. It has been shown [9] that small surface irregularities can cause rather large changes in the emittance characteristics. However, at the longer wavelengths of infrared radiation the emissivity is much less sensitive to small surface irregularities than at the shorter wavelengths of visible radiation. The smooth appearance of the surface when viewed by visible light was taken as an indication that the surface is practically optically smooth in the infrared region and that the errors due to surface roughness are negligible.

Because of the inertness of gold no surface oxide coating is possible. To remove any other possible surface layers the specimen was washed with distilled water and acetone and then heated to 800 °K for several hours before use. After this initial treatment the samples were maintained at temperatures above 100 °C until the measurements were completed. As a consequence it is felt that the state of the surface of the specimen was nearly ideal. There is of course some question as to the crystal structure of the optically important region of the metal near the surface, but the manner in which this changes the emittance of metals has not yet been established. Since the radiation observed was within 5 deg of normal to the specimen, polarization effects are negligible and were disregarded.

Errors due to incorrect emissivity values assigned to the specimen are more directly related to the actual experimental measurements. In the emissivity measurements the errors may be divided into three categories: (a) errors in wavelength measurement, (b) errors in energy measurement, and (c) errors in temperature measurements. The magnitude of these errors will be discussed separately below.

Wavelength Errors. With modern instrumentation and standard techniques of calibration it is a relatively simple matter to calibrate infrared spectrometers to within 0.02 μ over the entire range used in this work. Inasmuch as both the blackbody curve and the emissivity curve of the specimens are smooth curves with no sharp extremes or discontinuities, errors in wavelength should be entirely negligible in this work. The rather large spectrometer slit used at the shorter wavelengths, however, may introduce a nonnegligible error. The exact value of this error is difficult to determine and is in fact different for each wavelength and temperature. It is estimated to amount to no more than 1 percent.

Errors in Energy Measurements. The measurement of the energy given off by the specimen was accomplished by comparison with a blackbody as described in the section on experimental procedure. In making these measurements the temperatures were so arranged that the energy reaching the detector from the blackbody was nearly equal to that from the specimen. In this way instrumental errors due to amplifier or detector nonlinearity were practically eliminated. Almost all values reported are the average of several determinations with slightly different blackbody temperatures.

The important source of error in energy measurement is due to the signal to noise ratio. For measurements at higher temperatures and at wavelengths near the blackbody radiation maximum the signal to noise ratio is of course very favorable and uncertainties are quite negligible. For lower temperatures and especially for measurements near the long or short wavelength extremes of this work the signal to noise ratio becomes sufficiently small that rather large uncertainties are introduced into the results.

Because of the low energy levels involved in these measurements, especially at long wavelengths, stray radiation might be expected to cause appreciable errors. Use of a polyethylene-black filter to eliminate any short wave stray radiation proved, however, that stray radiation is quite negligible even at the longest wavelengths measured.

Errors in Temperature Measurement. In the determination of the emissivity by the method of equal radiance, the most important measurement is the temperature. Four temperatures must be measured or controlled; the temperature of the detector, the temperature of the room, the temperature of the specimen, and the temperature of the blackbody. The temperature of the room and of the detector can be measured to better than 1 deg K and the errors introduced by these measurements are small compared to the uncertainties in measurement of the temperature of the specimen and the blackbody. The temperature of the specimen is usually measured by an attached thermocouple and when the material is a metal with the form of a thin ribbon, the thermocouple may be welded on the back surface of the specimen. The thermocouple should be made of fine wires but even then there is some conduction of heat from the specimen. When the specimen can be heated to high temperatures the temperature gradients can be evaluated with an optical pyrometer. At lower temperatures the radiation from different areas of the specimen can be focused on the slit of the spectrometer and temperature gradients of the specimen can be detected and evaluated. In the application of this method to measurements on gold it was found that the variation of temperature was never greater than 5 deg K over the area used. The error introduced in the emissivity by a 5 deg error in temperature for a specimen at 800 °K has been calculated and the results are shown in figure 1. It will be noticed that the error is between 1 and 2 percent from 6 to 14 μ, but at shorter wavelengths the error increases rapidly reaching a value of 6 percent at 2 μ. When the specimen is at temperatures above 800 °K, the uncertainty in the emissivity will be smaller than those shown in figure 1 and the error will be greater for temperatures less than 800 °K.

A large source of uncertainty is introduced by errors in the temperature of the blackbody. This temperature should be measured to ± 1 °K. When the gold specimen is at a temperature of 800 °K, the blackbody is at 351 °K for equal energies being recorded at 10 μ. In the above example a change of 1 °K will produce an error of about 4 percent in the emissivity. With an uncertainty of 5 °K in the temperature measurement of the blackbody the errors become much greater as shown for different wavelengths in figure 2. It should be noted that large errors will be made in the determination of emissivities by this method unless the temperature of the blackbody is measured with an accuracy of the order of 1 °K.

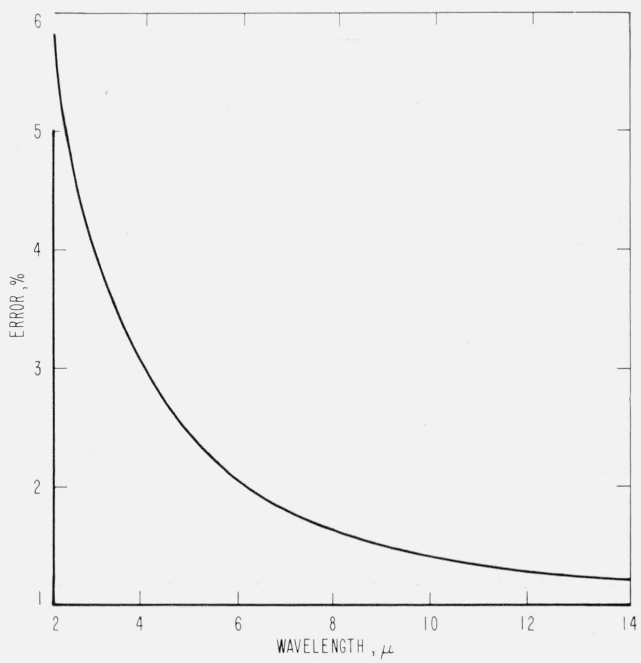

FIGURE 1. *Error in emissivity measurement at 800 °K resulting from an error in specimen temperature measurement of 5 °K.*

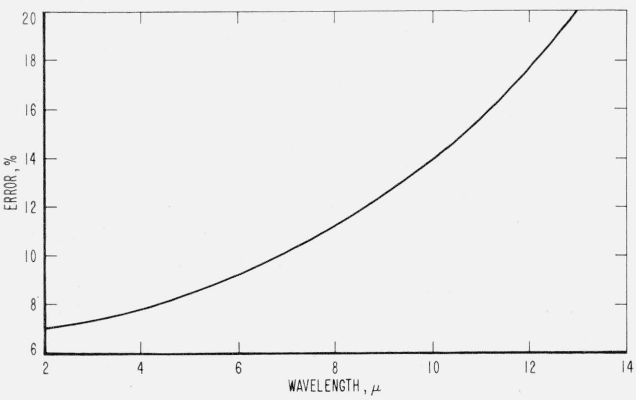

FIGURE 2. *Error in emissivity measurement at 1,000 °K resulting from an error in the blackbody temperature of 5 °K.*

4. Results

The normal spectral emissivity of gold has been measured over the spectral range from 4 to 13 μ. Table 1 lists the values of emissivity determined by this work. In order to make this table, smooth curves of emissivity versus temperature at constant wavelength and emissivity versus wavelength at constant temperature were drawn through the observed experimental values. The table entries were then read from these curves. The results for three temperatures are shown in figure 3. Experimental points which are the average of several determinations have been superimposed on the curves to show how closely the experimental values agree with the smoothed curves. Data were obtained at 50 °K temperature intervals so that much more data were used in making these curves than is shown in the figure.

The small increase in the emissivity curve at 9 μ is curiously unexpected, but appears consistently. This abnormality may be due to some unknown, consistent error in the data, but all attempts to eliminate it failed. Lameris [7] shows a similar rise in his data at about 10 μ (he made no observations between 7 and 10 μ).

There seems to be no other measurement of the emissivity or reflectivity of gold in the temperature range reported in this paper. Consequently, the only independent observations with which our results can be compared are the room temperature measurements for which reflectivity values are given in references 5 and 6. By extrapolation of the emissivity versus temperature curves it is possible to use the data of this work to obtain approximate emissivity values at lower temperatures. The extrapolated values are tabulated in table 2. These values are, of course, considerably less accurate than those given in table 1 since the extrapolation is not very reliable.

TABLE 1. *Normal spectral emissivity of gold*

λ_μ \ Temp. °K	550	600	650	700	750	800	850	900	950	1000
4.0	0.014	0.0147	0.0158	0.0169	0.0181	0.0193	0.0206	0.0219	0.0232	0.0246
4.5	.0142	.0151	.0163	.0174	.0184	.0196	.0208	.0221	.0234	.0248
5.0	.0145	.0155	.0165	.0176	.0187	.0198	.0210	.0223	.0236	.0249
5.5	.0145	.0155	.0165	.0176	.0187	.0198	.0210	.0223	.0236	.0249
6.0	.0142	.0152	.0162	.0173	.0183	.0195	.0208	.0221	.0235	.0249
6.5		.0150	.0160	.0170	.0181	.0193	.0206	.0220	.0234	.0249
7.0		.015	.0162	.0172	.0183	.0194	.0207	.0220	.0234	.0248
7.5		.016	.0169	.0178	.0187	.0198	.0209	.0221	.0234	.0246
8.0			.018	.019	.0197	.0206	.0215	.0225	.0235	.0244
8.5			.019	.020	.021	.0218	.0225	.0233	.0240	.0247
9.0					.022	.0228	.0235	.0242	.0249	.0256
9.5						.023	.0234	.0241	.0248	.0255
10.0						.022	.023	.0238	.0245	.0252
11.0							.023	.023	.024	.024
12.0									.023	.024
13.0										.023

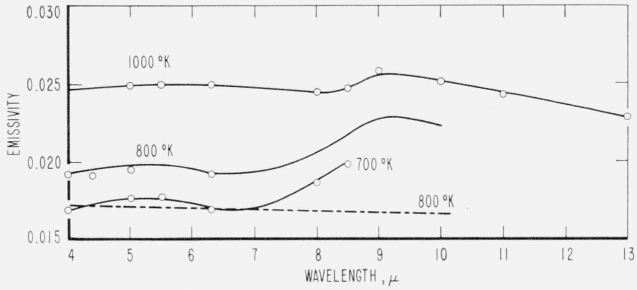

FIGURE 3. *Normal spectral emissivity of gold from 4 to 13 μ at 700, 800, and 1,000 °K.*
Dashed line is theoretical emissivity at 800 °K calculated from Drude equations.]

TABLE 2. *Approximate emissivity of gold obtained by extrapolation from higher temperature values*

λ_μ \ °K	200	300	400	500
4	0.0073	0.0090	0.0108	0.0127
5	.0083	.0099	.0117	.0135
6	.0082	.0098	.0115	.0133
7	.0085	.0100	.0117	.0134
8	.0108	.0123	.0138	.0154

5. Discussion

It is of considerable interest to compare the observed emissivity values of metals to those predicted by the classical free-electron model proposed by Drude [10]. Roberts has recently shown [11] that Drude's original consideration of several classes of electrons in some cases gives rise to calculated results more compatible with experiment; however, this idea has not been used in this experiment. According to the Drude model the refractive index (n) and the absorption coefficient (k) may be represented by the two equations

$$n^2-k^2=1-2\frac{Ne^2}{2\pi m^*}\frac{1}{\nu^2+\gamma^2}$$

and

$$nk=\frac{\gamma}{\nu}\frac{Ne^2}{2\pi m^*}\frac{1}{\nu^2+\gamma^2},$$

where

$$\gamma=\frac{Ne^2}{2\pi m^*}\rho$$

N=number of free electrons per unit volume,
e=electronic charge,
m^*=effective mass of electron,
ν=frequency, and
ρ=d-c electrical resistivity.

A simplification suggested by Hagen and Rubens is often used as a means of making emissivity calculations. This simplification rests upon the assumption that $\nu \ll \gamma$ and consequently is valid in the long wavelength (low frequency) region. This assumption leads to the result that

$$n=k=\left(\frac{1}{\rho\nu}\right)^{1/2}.$$

Substituting this in the equation for emissivity,

$$\epsilon=1-R=1-\frac{k^2+(1-n)^2}{k^2+(1+n)^2},$$

yields the result

$$\epsilon=2(\rho\nu)^{1/2}-2(\rho\nu)+\ldots\quad.$$

With appropriate changes of units this becomes the more familiar Hagen-Rubens equation,

$$\epsilon=0.365\left(\frac{\rho}{\lambda}\right)^{1/2}-0.0464\frac{\rho}{\lambda},$$

where ρ = resistivity in ohm centimeters and

λ = wavelength in centimeters.

Calculations based on the Hagen-Rubens equation give rise to values of the emissivity which are about 100 percent greater than the experimental values. As Schulz [12] has shown, the cause of this discrepancy is evident from an analysis of the assumptions made in the derivation of the Hagen-Rubens equation. Calculation of the value of γ indicates that ν is of the same order of magnitude and in fact is slightly larger than γ. This means that $n \neq k$. Measurements of n and k by Schulz for the near infrared confirms the fact $n \neq k$ at a wavelength of 1 μ. Calculations using Drude's equations indicate that n does not approach the value of k except for rather large wavelengths (about 100 μ). As a consequence it is not surprising that the Hagen-Rubens equation does not always yield correct values of the emissivity in the ordinary infrared region.

On the other hand, if the Drude equations are used to calculate the emissivity, better agreement with the measured values is obtained. The results of such a calculation for 800 °K are shown in figure 3. These calculations assumed one free electron per atom and that the effective electron mass (m^*) is equal to the usual electron rest mass.

The authors express their gratitude to William F. Roeser for his helpful suggestions concerning these measurements. Appreciation is also expressed to Robert Thibault who performed the very tangible service of transforming most of the raw data into values of emissivity.

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Publications of the National Bureau of Standards *

Selected Abstracts

Glass filters for checking performance of spectrophotometer-integrator systems of color measurement, H. J. Keegan, J. C. Schleter, and D. B. Judd, *J. Research NBS* **66A** *(Phys. and Chem.) No. 3, 203 (May–June 1962) 70 cents.*

A set of five specially selected colored-glass filters to identify variables of malfunction of photoelectric recording spectrophotometers equipped with tristimulus integrators have been standardized on a number of spectrophotometers corrected for all known errors (wavelength, zero, 100 percent, slit-width, inertia, back reflectance, and stray-energy). To these standardized spectrophotometric data definite amounts of these errors were deliberately introduced and converted to tristimulus values and chromaticity coordinates of the International Commission of Illumination system of colorimetry for Sources A, B, and C. Similar reductions show the effects of slit widths of 1, 5, 10, and 15 millimicrons on computed results both by the selected-ordinate method of 10, 30, and 100 ordinates, and by the weighted-ordinate method of 1, 5, 10, and 15 millimicron intervals. Duplicate sets of these glasses have been evaluated by visual comparison with this set of master standards, and are available as part of the Standard Materials Program of the National Bureau of Standards. By comparing the certified values of luminous transmittance and chromaticity coordinates for a set of these glasses with the values obtained on a particular integrator-spectrophotometer combination, the type and extent of instrumental errors may be evaluated.

Calibration of small grating spectrometers from 166 to 600 cm^{-1}, L. R. Blaine, E. K. Plyler, and W. S. Benedict, *J. Research NBS* **66A** *(Phys. and Chem.) No. 3, 223 (May–June 1962) 70 cents.*

In order to provide standards for the calibration of small grating spectrometers over the region from 166 to 600 cm^{-1}, tracings of the spectrum of atmospheric water vapor are presented. The lines are identified and tabulated. Wavenumbers obtained from energy levels derived from the best available high-resolution spectra are given, together with an indication of their relative reliability. The best lines are believed accurate to ± 0.03 cm^{-1}.

Purification by automatic gas chromatography, M. Tenenbaum and F. L. Howard, *J. Research NBS* **66A** *(Phys. and Chem.) No. 3, 255 (May–June 1962) 70 cents.*

A completely automatic apparatus has been developed for the preparative-scale purification of compounds by gas-liquid chromatography. A clock timer periodically activates a pump that injects a sample into the column. The recording potentiometer on which the chromatograph is traced has a switch mounted at the upper margin. Collection of the purified main component occurs when the recorder pen goes to the end of the scale and trips the switch. The sensitivity of the detector bridge circuit is adjusted so that only the trace caused by the major component will activate the collection process.

Toluene, ethylbenzene, and mesitylene were purified with the apparatus. Best results were obtained with toluene. In one pass through the apparatus, 92 percent of the impurities were removed from the toluene and the purified product was collected at a rate of 25 ml of liquid per day.

A diamond cell for X-ray diffraction studies at high pressures, G. J. Piermarini and C. E. Weir, *J. Research NBS* **66A** *(Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.*

A high pressure X-ray powder camera has been constructed. The instrument has been found to be useful for routing X-ray work, using molybdenum radiation, to pressures of approximately 60 kilobars. Previously reported transitions have been observed in silver iodide, potassium iodide, bismuth, and thallium. The high pressure forms and lattice parameters were found to be: AgI-f.c.c. (NaCl type), $a_0=6.067$A; KI-s.c. (CsCl type), $a_0=4.093$A; Tl-f.c.c. (NaCl type), $a_0=4.778$A; Bi structure not determined. These data confirm previous reports on the high pressure forms of AgI and KI. Data on Tl and Bi are apparently reported for the first time. The high pressure modifications were studied at the following approximate pressures which are not indicative of the point where the transition occurs: AgI-3.3 kilobars, KI-20 kilobars, Bi-28 kilobars, and Tl-60 kilobars. The pressure limit to which the unit can be used successfully has not been ascertained. It is believed to be much higher than the pressures reported. The present instrument is capable of producing powder diffraction patterns of materials of relatively high scattering power, giving data to $2\theta=35°$. High background on the X-ray powder patterns is believed to arise from scattering by the diamonds. This background may obscure weak diffraction rings. This effect may be reduced by screening, monochromatization, and other improvements in experimental technique.

Light source for producing self-reversed spectral lines, J. Sugar, *J. Research NBS* **66A** *(Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.*

A new light source has been developed which produces numerous self-reversed lines in both the first and second spectra of rare-earth elements. It consists of a pulsed arc discharge with a peak current of 75 amperes and an on-time of one millisecond per cycle. Resonance lines are nearly completely absorbed, and can be distinguished by this character. From spectrograms obtained with this light source, the ground states of Tb I and U II were determined, and those reported for Yb I, Yb II, Tm I, Tm II, and U I were confirmed.

Thermal conductivity of gases. I. The coaxial cylinder cell, L. A. Guildner, *J Research NBS* **66A** *(Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.*

By combining appropriate geometric configuration and mathematical analysis with improved measuring techniques, the cell constant of a coaxial cylinder thermal conductivity cell was determined within 0.1 percent.

An analysis of the rate of heat transfer in such a cell showed a way to treat the data so that the error contribution of experimental deviations from idealized conditions is kept small. The principal considerations are:

1. That heat transport by convection is significantly large in a dense gas. This transport was analyzed mathematically from basic principles. The agreement of experimental results with the analysis indicated that the expressions are valid and that the convective heat transport could be accounted for with little more error than was involved in the precision of the heat transfer measurements.
2. That the heat transfer in a vacuum corresponds to the heat transfer by radiation and solid contacts in the presence of a gas. The uncertainty was that associated with the accuracy of determining the vacuum values.
3. That other effects were small enough to be computed and corrected for without increasing the uncertainty of the values of the thermal conductivity.

Thermal conductivity of gases. II. Thermal conductivity of carbon dioxide near the critical point, L. A. Guildner, *J. Research NBS* **66A** *(Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.*

The thermal conductivity of CO_2 has been measured in a coaxial cylinder cell as a function of pressure over a range of temperatures from 3.66 to 75.26 °C. Particular attention was given to the measurements from 1 to 9 deg C above the critical temperature at pressures closely spaced to include the critical density.

The thermal conductivity of $CO_{2(g)}$, near the critical point is very large compared to one atmosphere values around room temperature. At 1 deg C above the critical point the thermal conductivity reaches a maximum at the critical density. This maximum is greater than the maxima at higher temperatures. At 75.26 °C, 44 deg C above the critical temperature, little unusual increase at the critical density was observed.

The rate of heat transport by convection in the critical region is also very large. This problem was studied carefully in order that the temperature differences used were restricted to the region of laminar flow, and that appropriate extrapolation procedures were used to find the rate of heat transfer by thermal conduction alone.

Also, at densities and temperatures away from the critical region, new thermal conductivity values were obtained.

Derivation of the relaxation spectrum representation of the mechanical response function, R. S. Marvin, *J. Research NBS* **66A** *(Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.*

Relaxation spectra have been used in both the presentation and interpretation of measurements of the mechanical properties of rubberlike polymers.

Hindsight technique in machine translation of natural languages, I. Rhodes and F. L. Alt, *J. Research NBS* **66B** *(Math. and Math. Phys.) No. 2, 47 (Apr.–June 1962) 75 cents.*

In the proposed system for automatic syntactic analysis of Russian sentences developed at the National Bureau of Standards, the computer splits each Russian word into stem and ending and combines the information obtained from these two elements into a morphological description of the word, frequently containing several alternatives. The decision among such alternatives is normally made on the basis of "predictions" arising from preceding words of the same clause. There are, however, cases in which no prediction is available to account for a word, e.g., when the object of a verb occurs before the verb itself. In such a case, instead of the usual prediction of the object, we need "hindsight". Also, it may happen that more than one of the morphological alternatives of a word agrees with predictions; or that a single morphological alternative agrees with several predictions; or that only one of them agrees, yet there is a suspicion that the agreement is spurious; or that no agreement at all is found. It turns out that the alternating use of prediction and hindsight techniques overcomes most of these troubles.

Graphs for determining the power of Student's *t*-test, M. C. Croarkin, *J. Research NBS* **66B** *(Math. and Math. Phys.) No. 2, 59 (Apr.–June 1962) 75 cents.*

This paper presents charts for determining the operating characteristics of Student's t-test. For a fixed level of significance α, the charts give constant contours of the power β depicting the number of observations plotted against a function of the difference in means. Both the one-sample and the two-sample (equal sample sizes) cases are treated for all combinations of

$$\alpha = .01,\ .02,\ .05,\ .10,\ .20 \text{ and}$$
$$\beta = .10,\ .50,\ .90,\ .95,\ .99 \text{ except}$$
$$(\alpha,\beta) = (.10,\ .10),\ (.10,\ .20).$$

The graphs were constructed for two-sided tests but within the given accuracy are equally applicable to one-sided tests.

On the role of the process of reflection in radio wave propagation, F. du Castel, P. Misme, A. Spizzichino, and J. Voge, *J. Research NBS* **66D** *(Radio Prop.) No. 3, 273 (May–June 1962) 70 cents.*

Nature offers numerous examples of irregular stratification of the medium for the propagation of radio waves. A study of the process of reflection in such a medium distinguishes between specular reflection and diffuse reflection. The phenomenon of trans-horizon tropospheric propagation offers an example of the application of such a process, necessary for the interpretation of experimental results. Other examples are those of ionospheric propagation (sporadic-E layer) and propagation over an irregular ground surface (phenomenon of albedo).

Currents induced on the surface of a conducting circular cylinder by a slot, G. Hasserjian and A. Ishimaru, *J. Research NBS* **66D** *(Radio Prop.) No. 3, 335 (May–June 1962) 70 cents.*

This paper is a partial study of currents induced on circular, conducting cylinders by narrow radiating slots. First, a brief and general formulation of the radiation fields of slots on cylinders is made. Then, the problem of an infinite axial slot is examined thoroughly for all cylinder sizes. An expansion for the fields, very close to the slot, on large radius cylinders, is also obtained. Sample computations are made, for various ranges of cylinder radius, and the order of the errors is discussed.

The problem of a circumferential slot, of constant excitation, is also considered. An asymptotic expansion obtained for this case yields the surface current distribution for values of axial distances that are smaller than the square of the circumference of the cylinder.

Since one of the objectives of this study is to determine mutual coupling between two slots on a cylinder, the last section presents a formulation of the equivalent network in terms of the surface and feed line currents.

The interaction between an obliquely incident plane electromagnetic wave and an electron beam in the presence of a static magnetic field of arbitrary strength, K. H. B. Wilhelmsson, *J. Research NBS* **66D** *(Radio Prop.) No. 4, 439 (July–Aug. 1962) 70 cents.*

The purpose of the paper is to study theoretically the interaction between an obliquely incident plane electromagnetic wave and an electron beam. We assume that a static magnetic field of arbitrary strength is present in the axial direction.

Machine computations made for the case of a cylindrical electron plasma show that resonances occur in the backscattering cross section as a function of the angle of incidence of the plane wave. The dependence of the resonance angles on the plasma frequency for fixed gyro frequency suggests a possibility to utilize the results of the investigation for diagnostics of a cylindrical plasma.

The impedance of a circular loop in an infinite conducting medium, M. B. Kraichman, *J. Research NBS* **66D** *(Radio Prop.) No. 4,* 499 *(July–Aug. 1962) 70 cents.*

Expressions are derived for the resistance and reactance of a circular loop of thinly insulated wire which carries a uniform current and is immersed in a conducting medium. The result for the resistance is compared with that known for a circular loop in a spherical insulating cavity.

Calibration procedures for direct-current resistance apparatus, P. P. B. Brooks, *NBS Mono. 39 (Mar. 1962) 40 cents*

The equipment and procedures used at NBS for the precise measurement of d-c resistance are explained in detail. The specific application of these procedures to the calibration of bridges and potentiometers is explained. It is expected that this paper will be of considerable help to the many company and governmental standardizing laboratories now being established.

Thermocouple materials, F. R. Caldwell, *NBS Mono. 40 (Mar. 1962) 30 cents.*

Thermocouple materials are considered that are used primarily as immersion temperature sensors in the range from 0 °C up. Included are the conventional thermocouples that have survived since the beginnings of the art of thermoelectric temperature measurement, newer noble metal thermocouples, and thermocouples of refractory metals for use in the extreme range for immersed sensors. Thermocouples for thermoelectric generators are not considered, nor are the types commonly used chiefly in radiation receivers such as those containing antimony, bismuth, and their alloys. Because of the wide use and increasing popularity of ceramic-packed thermocouples in metal sheaths, they are included.

Limitations of the thermocouple wires are given as to range, stability, environment including atmosphere, magnitude of thermoelectric emf, and accuracy of commercially available materials of standard and extra quality. In addition, properties of the separate elements that are pertinent to the selection or use of thermocouples have been compiled. Among these are: chemical behavior, mechanical properties, specific heat, density, thermal conductivity, thermal coefficient of expansion, emissivity, electrical resistivity, and magnetic and catalytic properties.

In the case of the ceramic-packed thermocouples the following properties are presented: temperature range of the sheath, mechanical properties of the sheath, kinds of packed insulation, resistance between thermocouple wires and between wires and sheath, minimum bending radius of the packed stock, gas-tightness of the packed insulation, and types of measuring junctions available, i.e., grounded, ungrounded, bare, totally enclosed, stagnation mounting, etc.

Not all of the above information is presented for all thermocouples, but all that is readily available in the general literature catalogs, and by private communication is included. Limitations on use of thermocouples normally are given in the text, and properties of the materials generally are presented in tables.

A transistor-magnetic core digital circuit, E. W. Hogue, *NBS Tech. Note 113 (PB161614) (1961) $3.00.*

A digital amplifier of simple noncritical design incorporating an emitter-follower and a small magnetic amplifier is described. Timing and some of the operating power are provided by a 300-kc 2-phase 7-volt sine-wave source. In structure and mode of operation, the amplifier is particularly suited for use with two-level diode gating to provide the AND and OR logical operations. A NOT-amplifier provides negation with amplification. The volt-second transfer characteristic of the stage critically determines the stability of propagation of binary signals. Factors governing the required shape of this transfer characteristic are discussed.

A survey of the literature on heat transfer from solid surfaces to cryogenic fluids, R. J. Richards, W. G. Steward, and R. B. Jacobs, *NBS Tech. Note 122 (PB161623) (1961) $1.25.*

A bibliography of 156 references on heat transfer from solid surfaces to fluids and related phenomena is presented. Heat transfer data obtained from experimental work on cryogenic fluids are presented in graphical form. The theoretical and empirical formulations appearing in the references are presented. In those cases where sufficient information is available to make numerical computations, the formulations are presented graphically to permit comparison with the results of the experimental work.

Functional and design problems of the NBS RF voltage bridge, L. F. Behrent, *NBS Tech. Note 123 (PB161624) (1961) $1.00.*

A detailed presentation is given of the practical solutions to the design and operating problems encountered in constructing a Thermistor Bridge similar to that used by the NBS for RF Voltage Standardization. Measurement and operating techniques, critical structural features, as well as the proper use of available components are discussed.

Evaluation of convolution integrals occurring in the theory of mixed path propagation, J. R. Johler and C. M. Lilley, *NBS Tech. Note 132 (PB161633) (1961) $1.00.*

The theory of propagation of electromagnetic waves around a sphere treats the smooth homogeneous case, i.e., the case in which the surface impedance of the sphere is uninterrupted by an abrupt change in conductivity such as a land/sea boundary. It is known, however, that such a theory can be extended to treat inhomogeneous, irregular terrain by formulating certain convolution integrals which utilize the smooth homogeneous formulas. The evaluation of these integrals can be accomplished with dispatch on a large-scale electronic computer with the aid of numerical analysis techniques.

The particular case of a land/sea boundary in a smooth, spherical surface is illustrated for a variety of cases by evaluating the convolution integrals on a large-scale computer.

Historical survey of fading at medium high radio frequencies, R. K. Salaman, *NBS Tech. Note 133 (PB161634) (1962) 75 cents.*

This condensed historical survey contains information on many of the articles concerned with HF and MF ionospheric fading, which have appeared in the literature through 1960. The primary emphasis is on an oblique incidence propagation, although many articles pertaining to fading at vertical and near vertical incidence (incorporating winds experiments) are also included. No effort was made to include the fading and scintillation studies in the literature of radio astronomy and satellite propagation, where they pertain to determining the characteristics of the ionosphere, and not to MF and HF communication.

Information is available on the origin of fading, the approximate dependence of fading rate on distance and frequency, and the amplitude distributions for particular transmission paths. This information is, however, not sufficient either for a realistic estimate of the performance of communication systems or for signal design consistent with the medium statistics.

With respect to communication systems at MF and HF, information which is needed for analysis and design includes statistics on the amplitude distribution and the fade rate, depth, and duration. Such information should be obtained as a function of propagation mode, frequency relative to the predictable MUF, time, season, geographic location, and sunspot cycle.

A study of F2-layer effects as observed with a Doppler technique, K. Davies, J. M. Watts, and D. H. Zacharisen, *J. Geophys. Research* **67,** *601–609 (Feb. 1962).*

Changes in the height and shape of the ionosphere produce variations in frequency, at a receiver, of waves emitted from a stable sender. WWV–10, WWV–15, WWV–20, and WWVH–10 have been recorded, at Boulder, on slow-moving magnetic tape. By rapid playback the Doppler frequency is converted into an audio frequency and the spectrum analyzed by conventional techniques.

Records obtained by this technique are presented to illustrate the phenomena observed during magnetically quiet and disturbed periods. Experimental effects associated with solar flares and magnetic sudden commencements are presented. The frequency dependence of the frequency variations is shown to give information concerning the height location of the associated ionospheric effects.

Displacement and strain-energy distribution in a longitudinally vibrating cylindrical rod with a viscoelastic coating, P. Hertelendy, *J. Appl. Mechanics, No. 61–WA–30 (1962).*

A numerical solution by R. M. Davies of the Pochhammer frequency equation is used to determine the displacement and strain energy distribution across the cross-section of an infinite elastic circular cylindrical rod for a number of wavelengths of the first, second, and third modes of symmetric longitudinal vibration. With these results the effect of a thin uniform layer of damping material on the surface is investigated. It is shown that with proper choice of bar material and frequency range the attenuation of a progressive wave is virtually independent of the bulk modulus viscosity parameter, enabling one to relate the shear viscosity directly to the rate of signal attenuation.

Superconducting magnets, R. H. Kropschot and V. Arp, *Cryogenics* **2,** *No. 1, 1–15 (Sept. 1961).*

The feasibility of employing superconducting windings for use in electromagnets is discussed. The principal problem is one of finding a material with a sufficiently high critical field so that the magnetic field does not quench the superconductor at the desired operating condition. For fields up to 20 kilo-oersteds materials such as Niobium and some of the superconducting alloys appear practical. For fields greater than 20 kilo-oersteds superconducting films having a thickness less than the penetration depth are considered. Although theory and experiment on thin films are very meager a distinct possibility exists that these materials can be used to produce "air core" solenoids of up to 90 kilo-oersteds. The power required (refrigeration only) to operate a magnet of this type may be considerably less than for a conventional ambient temperature magnet.

Parametric behavior of an ideal two-frequency varactor, G. F. Montgomery, *Proc. IRE* **50,** *No. 1, 78–80 (1962).*

The Manley-Rowe equations for a lossless varactor network yield little information for the two-frequency case. With the assumption of a linear signal termination, it is shown that the ratio of signal and pump frequencies must be M/2, where M is an integer. For M odd, a regenerative network is possible at the signal frequency. For M even, the network is possibly regenerative or nonregenerative. Other frequency ratios are not possible; frequency division is not possible except for regenerative division by 2. The effects of strong pumping are predictable if the varactor characteristic is given.

Design of retarding field energy analyzers, J. A. Simpson, *Rev. Sci. Instr.* **22,** *No. 12, 1283–1293 (Dec. 1961).*
Retarding field analysers of the plane parallel plate, the spherical condenser, the Faraday cage, and the filter lens types are examined in some detail. The often neglected lens effect of the hole in the plane parallel plate through which the beam passes is shown to have significant effect on the energy resolution. The previous analysis of the spherical condenser is extended to the hemispherical case and the effect of the aperture in the inner sphere calculated. It is shown that for certain relations between the sphere sizes and the position of the source very high resolution may be obtained. The general restrictions on the performance of imaging retarding fields are considered and a design procedure based upon empirical knowledge of immersion lenses is given.

Radiation beam mapping with photographic film, W. L. McLaughlin, *Radiology* **78,** *No. 1, 119–120 (Jan. 1962).*
An experiment was carried out at the National Bureau of Standards to examine with photographic film the uniformity of X- and γ-ray beams used in the calibration of radiation instruments. By exercising certain precautions in film selection, positioning, processing, and photometric measurement, it was possible to determine the intensity distribution across the beams with an accuracy of one percent.

Stress-strain relationships in yarns subjected to rapid impact loading. Part VIII: Shock waves, limiting breaking velocities, and critical velocities, J. C. Smith, J. M. Blandford, and K. M. Towne, *Textile Research J.* **32,** *No. 1, 67–76 (Jan. 1962).*
An impact velocity just sufficient to cause immediate breakage in a filament impacted in tension is called a critical velocity. Theories required for calculating critical velocities from stress-strain data valid under critical velocity impact conditions are reviewed and extended. Critical velocity estimates are then calculated for some textile yarns using stress-strain data obtained at impact speeds near 40 m/sec. The velocities obtained range in value from approximately 100 m/sec for cotton sewing thread and glass fiber yarn to approximately 300 m/sec for some vinal, rayon tire cord, acrylic, and nylon yarns. Theory is developed for estimating critical velocity from the specific breaking energy obtained by high-velocity impact tests. It is shown that the estimate in this case is high if the stress-strain curve is predominantly concave downward, low if the stress-strain curve is predominantly concave upward, and equal to the critical velocity estimate if the curve is linear. Critical velocities are also estimated from stress-strain data obtained at 100 %/min straining rates and compared with calculations from high velocity impact data. Good agreement is found in many cases.

Current-limited rectifiers, G. F. Montgomery, *Proc. IRE* **50,** *No. 2, 190–193 (Feb. 1962).*
Several ac rectifier circuits have the property, inherent in the rectification process, of limiting their output current to a specified maximum. They are technically simple and can be used as the foundation for power supplies that remain undamaged and absorb little power with a short-circuited load. In combination with a dc regulator, such a rectifier provides a constant-voltage supply with desirable overload characteristics. A modified bridge rectifier is especially useful.

Statistical problems arising in the establishment of physical standards, W. J. Youden, *Proc. Fourth Berkeley Symp. on Math. Statistics and Probability III, 321–335 (1961).*
The establishment and maintenance of physical standards is indispensable for scientific research, commerce and industry. The first standards were sufficiently ahead of the existing needs so that questions of precision and accuracy were hardly raised. In recent years the requirements of research and industry have become extremely exacting. Questions of precision and accuracy are now raised on every hand.
Among the statistical problems connected with the development of improved physical standards are the estimation of measurement precision; the design of experiments to provide information on the accuracy; and the reconciliation of results obtained in the national laboratories of the countries undertaking this work. This paper reviews and illustrates by actual examples, some of the ways in which statistical methodology can make contributions in this field.

Rapid method for interpolating refractive index measurements, O. N. Stavroudis and L. E. Sutton, *J. Opt. Soc. Am.* **51,** *No. 3, 368–370 (Mar. 1961).*
This paper describes a method for fitting measured values of refractive index versus wavelength to a two-termed Sellmeier dispersion formula,

$$n^2=1+\frac{A_1\lambda^2}{\lambda^2-\lambda_1^2}+\frac{A_2\lambda^2}{\lambda^2-\lambda_2^2}$$

by a modified least squares procedure. By clearing fractions and introducing auxiliary variables, a linear expression is obtained, the least squares solution of which provides a starting point for a linear improvement routine. The process is very fast and is particularly applicable to high-speed digital computers. While the results do not represent the ultimate in obtainable accuracy, they provide a starting point for obtaining better fits using a more complex formula.

A specimen for use in investigating the stress-corrosion cracking of metals at elevated temperatures, H. L. Logan, *Materials Research and Standards (ASTM Bull.)* **2,** *No. 2, 98–100 (Feb. 1962).*
A hollow specimen that contains the corrodent under pressure and is subjected to known tensile stresses at known temperatures is described.
Type 304 stainless steel specimens of this design, exposed to distilled water containing 20,000 ppm of chloride, and oxygen, in the temperature range of 455° to 615° F, generally developed stress-corrosion cracks under mechanically applied stresses of 25,000 and 30,000 psi. Stress-corrosion cracking was more severe at stresses of 30,000 psi than at the lower stress level. The presence of oxygen was necessary for the development of cracks.

The three-dimensional nature of boundary-layer instability, P. S. Klebanoff, K. D. Tidstrom, and L. M. Sargent, *J. Fluid Mechanics* **12,** *Pt. 1, 1–34 (1962).*
An experimental investigation is described in which principal emphasis is given to revealing the nature of the motions in the nonlinear range of boundary layer instability and the onset of turbulence. The experimental method consisted of introducing in a two-dimensional boundary layer on a flat plate at imcompressible speeds three-dimensional disturbances under controlled conditions using the vibrating ribbon technique, and studying their growth and evolution using hot-wire methods. It is definitely established that associated with the nonlinear three-dimensional wave motions there are longitudinal vortices. Existing theoretical considerations are evaluated, and the results support the point of view that the principal nonlinear mechanism involves the nonlinear behavior of a three-dimensional perturbation. It is also demonstrated that the breakdown of the wave motion to turbulence is a consequence of a new instability which arises in the aforementioned three-dimensional wave motion. It is also shown that the results obtained from the study of controlled disturbances are equally applicable to "natural" transition.

Dynamic behavior of a simple pneumatic pressure reducer, D. H. Tsai and E. C. Cassidy, *J. Basic Eng., 253–264 (June 1961).*
This paper presents an analysis of the dynamic behavior of a simple pneumatic pressure reducer. Both the non-linear and the linearized problems were studied. Some experimental results were also obtained on a working reducer model to check the validity of the analysis. The agreement between the non-linear solutions and the experimental results was satisfactory. The non-linear and the linearized solutions

were compared in detail so as to bring out the essential features of the dynamic behavior in both cases. The stability problem was also studied, and a set of stability criteria for the linearized case was formulated in terms of the design and operating parameters of the reducer. In the few sample cases studied, these criteria gave correct qualitative predictions of the stability of the reducer in both the linearized case and the non-linear case. The flow forces on three typical flow-metering valves were also determined by experimental measurements (Appendix 2). These results were used in the analytical part of the paper.

Effect of porosity on Young's modulus of alumina, F. P. Knudsen, *J. Am. Chem. Soc.* **45,** *No. 2, 94–95 (Feb. 1962).*
A graphic compilation is presented of available data of the Young's moduli of porous polycrystalline alumina at room temperature. The apparent dependence of Young's moduli (E) or porosity (P) could be satisfactorily approximated by the equation

$$E \text{ (in kilobars)}=4102\ e^{-3.95P}.$$

A new approach to the mechanical syntactic analysis of Russian, I. I. Rhodes, *Mech. Transl.* **6,** *33–50 (Nov. 1961).*
The Mechanical Translation scheme used at the National Bureau of Standards has dealt so far only with the syntactical aspects of the problem. The report describes how the difficulties encountered in this portion of the task are being overcome. Mention is made of the additional difficulties, belonging to the field of semantic analysis, which have not yet been considered by the NBS translation group.

Double probe measurements of ionization in active nitrogen, H. P. Broida and I. Tanaka, *J. Chem. Phys.* **36,** *No. 1, 236–238 (Jan. 1962).*
Electron temperatures and ion densities have been measured in nitrogen afterglows in a flow system at short times after the discharge. In pure nitrogen a maximum occurs in the ionization density and in the electron temperature at 5 to 10 msec after the discharge. The position of this maximum coincides with the visible short-duration nitrogen afterglow in which N_2^+ emission is prominent. Small amounts of added impurity decrease this ion density but cause an increase in the ion density at longer times, reaching a second maximum at 80 to 100 msec after the discharge. These results show that ions and electrons are being produced continuously in nitrogen afterglows and that the rate of production is affected strongly by impurities.

Fitting refractive index data by least squares, L. E. Sutton and O. N. Stavroudis, *J. Opt. Soc. Am.* **51,** *No. 8, 901–905 (Aug. 1961).*
The accessibility of high speed computing machinery makes practicable the use of a routine for the least-squares fitting of a three-term Sellmeier equation to a set of experimentally determined values of index of refraction. The constants of a two-term Sellmeier equation are evaluated by a method described previously. These are then used in a preliminary fitting of another term. The rough fit is then improved by an iterative process which includes an acceleration technique to speed convergence to the final result. In a typical example the average residual of index is only about 2×10^{-5} for 46 wavelengths from 0.2652 microns to 10.346 microns.

Maxwell and modern colorimetry, D. B. Judd, *J. Photographic Sci.* **9,** *No. 6, 341–352 (Nov.-Dec. 1961).*
The methods used by Maxwell to reduce colour-matching data from rotating sector discs (Maxwell discs) so as to represent the chromaticity of the unknown colour on a chromaticity diagram (Maxwell triangle) form the basis of modern colorimetry. Maxwell's determination of the colour-matching functions for two observers carried out by these methods is found, when expressed in terms of flux units instead of the slit-width units used by Maxwell, to be in essential agreement with the 1931 CIE standard observer defining the colour scales currently used internationally.

Dielectric properties of solid polymers, A. J. Curtis, *SPE Trans., 82–85 (Jan. 1962).*
Basically, the study of dielectric relaxation, by the measurement of dielectric constant and loss index over a temperature and frequency range, can give information about motions in polymers involving orientation of polar segments. Insofar as motion of polymers studied by other methods involves motion of polar segments, the results and interpretations should agree with those from dielectric relaxation data.

A statistical comparison of the wearing characteristics of two types of dollar notes, E. B. Randall, Jr., and J. Mandel, *Materials Research and Standards (ASTM Bull.)* **2,** *No. 1, 17–25 (Jan. 1962).*
Two types of one-dollar notes, printed by two different methods on two different papers, are in circulation. The wearing properties of these dollar notes have been compared by a statistical method based on the concept of survival curves.
Dollar notes in circulation in the Washington, D.C. area were sampled. Data from 15 samplings, or a total of 30,000 notes, were obtained after the notes had been sorted according to type (old or new), fitness and age.
It is concluded that the median life of the new dollar note is approximately 30 percent longer than that of the old type of note using the usual Treasury standards for the evaluation of fitness.

Non-additivity in two-way analysis of variance, J. Mandel, *J. Am. Stat. Assoc.* **56,** *878–888 (Dec. 1961).*
In two-way classification analysis of variance situations there often exists a systematic type of row column interaction. A model is proposed in which the interaction is of the type $Q_i\gamma_i$ where Q_i is a parameter of the ith row, not necessarily associated with the main effect for rows, and γ_i is the main effect for column j. The analysis of data according to this model is given, including estimation and tests of significance. The model is more general than that involved in Tukey's "one degree of freedom for non-additivity" and includes the latter as a special case. The relationship between the two methods is discussed. Applications of the method to different types of problems are mentioned and a numerical example is included.

On the impedance of long wire suspended over the ground, J. R. Wait, *Proc. IRE* **49,** *No. 10 (Oct. 1961).*
Much has been written over the years on the subject of the impedance of wires lying on the ground or suspended above it. The possibility that a long horizontal wire will be a feasible radiator of very-low-frequency radio waves has reopened interest in the problem. It is the purpose of this note to outline a rather simple solution for the impedance of an infinitely long wire located at a height h over a homogeneous flat ground.

Automatic screening of normal and abnormal electrocardiograms by means of a digital electronic computer, H. V. Pipberger, R. J. Arms, and F. W. Stallmann, *Prof. Soc. Experimental Biology and Medicine* **106,** *130–132 (1961).*
The spatial ventricular gradient was determined in 256 electrocardiograms by means of a digital electronic computer. This automatic procedure allowed separation of normal and abnormal records with a high degree of precision. 98 percent of all cases with old myocardial infarctions, which are of prime interest in electrocardiographic diagnosis, were recognized as abnormal.

Electromagnetic bearing, H. Sixsmith, *Rev. Sci. Instr.* **32,** *1195–1197 (Nov. 1961).*
A shaft is supported by means of a laminated rotor which is magnetically suspended inside a four pole laminated stator. The diameter of the rotor is 1¾″ and the radial clearance is 0.002″. The position of the shaft is sensed with the aid of four quadrant electrodes which surround the shaft with a small radial clearance. Each electrode provides part of the tuning capacity of an R.F. tuned circuit which is tuned to one side of its resonance peak with respect to an R.F. generator. The R.F. signal is detected and amplified to provide the control current in the corresponding winding on the stator. The bearing was found to run smoothly up to 23000 rpm. With further development, a reliable and useful bearing should result.

Traveling pressure waves associated with geomagnetic activity, P. Chrzanowski, G. Greene, K. T. Lemmon, and J. M. Young, *J. Geophys. Research* **56,** *No. 11, 3727–3733 (Nov. 1961).*

Traveling atmospheric pressure waves with periods from 20 to 80 seconds and pressure amplitude from about 1 to 8 dynes/cm^2 have been recorded at a microphone station at Washington, D.C., during intervals of high geomagnetic activity. Trains of these waves can be expected at Washington from a quadrant approximately centered on north whenever the magnetic index K_p rises to a value above 5. Their horizontal phase velocity across the station is usually higher than the local speed of sound. During two 'red' auroras, clearly visible at Washington and at lower latitudes, the 20- to 80-second-period waves were accompanied by longer period, higher pressure, and much slower traveling pressure disturbances. Observational data on the wave systems are presented and discussed.

Use of an operational amplifier with Helmholtz coils for reducing ac induced magnetic fields, L. A. Marzetta, *Rev. Sci. Instr.* **32,** *No. 11, 1192–1195 (Nov. 1961).*

A feedback system is described for canceling magnetic fields resulting from alternating currents. The design features of an operational amplifier are offered. In addition the nature of the phase shift contributed by mutual inductance elements in the feedback path is discussed. Magnetic fields with a flux density of one milligauss can be reduced by about two orders of magnitude with the system.

Dielectric properties of polyamides, A. J. Curtis, *J. Chem. Phys.* **34,** *No. 5, 1849–1850 (May 1961).*

The dielectric relaxation in two polyamides has been studied over a temperature range from −100° to 175° C and a frequency range from 50 cps to 10 Mc/s. The effects of various thermal treatments on the relaxation behavior have been studied. The polyamides were poly(hexamethylene adipamide) and poly(hexamethylene sebacamide). Four relaxation phenomena have been identified. Mechanical relaxation processes are compared with the dielectric phenomena and possible molecular mechanisms are discussed.

Other NBS Publications

Journal of Research 66A (Phys. and Chem.) No. 3 (May–June 1962) 70 cents.

Glass filters for checking performance of spectrophotometer-integrator systems of color measurement. H. J. Keegan, J. C. Schleter, and D. B. Judd. (See above abstract.)
Calibration of small grating spectrometers from 166 to 600 cm^{-1}. L. R. Blaine, E. K. Plyler, and W. S. Benedict. (See above abstract.)
Franck-Condon factors to high vibrational quantum numbers II: SiO, MgO, SrO, AlO, VO, NO. R. W. Nicholls.
Oxidation of aldoses with bromine. H. S. Isbell.
An analysis of the solid phase behavior of the normal paraffins. M. G. Broadhurst.
Methylene groups in determination of disulfide and methylene sulfide crosslinks in polycaprolactam fibers. S. D. Bruck.
Purification by automatic gas chromatography. M. Tenenbaum and F. L. Howard. (See above abstract.)
High resolution investigation of some infrared bands of carbon disulfide. D. Agar, E. K. Plyler, and E. D. Tidwell.

Journal of Research 65A (Phys. and Chem.) No. 4 (July–Aug. 1962) 70 cents.

Dielectric properties of semicrystalline polychlorotrifluoroethylene. A. H. Scott, D. J. Scheiber, A. J. Curtis, J. I. Lauritzen, Jr., and J. D. Hoffman.
Thermal degradation of fractionated high and low molecular weight polystyrenes. S. L. Madorsky, D. McIntyre, J. H. O'Mara, and S. Straus.
Synthesis of 2-propoxy-5-methylbenzoic acid. G. M. Brauer and L. Simon.
Gamma-ray distribution from oriented cerium-141. J. F. Schooley, D. D. Hoppes, and A. T. Hirshfeld.
Light source for producing self-reversed spectral lines. J. Sugar. (See above abstract.)
A diamond cell for X-ray diffraction studies at high pressures. G. J. Piermarini and C. E. Weir. (See above abstract.)
Thermal conductivity of gases. I. The coaxial cylinder cell. L. A. Guildner. (See above abstract.)
Thermal conductivity of gases. II. Thermal conductivity of carbon dioxide near the critical point. L. A. Guildner. (See above abstract.)
Derivation of the relaxation spectrum representation of the mechanical response function. R. S. Marvin. (See above abstract.)
Intermediate phases in superconducting niobium-tin alloys. L. L. Wyman, J. R. Cuthill, G. A. Moore, J. J. Park, and H. Yakowitz.

Journal of Research 66B (Math. and Math. Phys.) No. 2, (Apr.–June 1962) 75 cents.

Hindsight technique in machine translation of natural languages. I. Rhodes and F. L. Alt. (See above abstract.)
An extension of Jensen's theorem for the derivative of a polynomial and for infrapolynomials. O. Shisha.
Two matrix eigenvalue inequalities. S. Haber.
Graphs for determining the power of Student's *t*-test. M. C. Croarkin. (See above abstract.)

Journal of Research 66D (Radio Prop.) No. 3, (May–June 1962) 70 cents.

A theory of radar reflections from a rough moon. D. F. Winter.
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