

# An Absolute Temperature Scale From 4 °K to 20 °K Determined From Measurements With an Acoustical Thermometer\*

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At NBS an acoustical thermometer has been used to obtain values of temperature at every degree from 5 to 20 °K as a basis for a temperature scale. This scale has been compared with four other temperature scales in the region from 10 to 20 °K. Since the acoustical thermometer is an entirely new approach to precision thermometry in this range the comparison of its resulting scale with scales based upon gas thermometry from 12 to 20 °K is significant. Indications of inaccuracies in the equilibrium hydrogen vapor pressure scales, and also in the He<sup>4</sup> vapor pressure scale, are presented.

For a number of years the National Bureau of Standards has been engaged in a low temperature thermometry program, one objective of which is the establishment of a primary temperature scale which would include the region 4 to 14 °K. After consideration of the relative merits and disadvantages of conventional gas thermometry, it was decided that an investigation of temperature measurements derived from the speed of sound in helium gas should be initiated. In addition to the application in the range 4 to 14, the acoustical thermometer should also provide an independent check above 14 °K and below 4 °K. The "acoustical interferometer" appeared to be the best instrument for the experimentation.

A general discussion of the acoustical interferometer has been presented by J. L. and E. S. Stewart [1];<sup>1</sup> more specific application to low temperatures has been reported by Van Itterbeek and his co-workers [2–4]. While it is not the intention of the present paper<sup>2</sup> to discuss the acoustical interferometer as an operating instrument, it is necessary to mention that it involves a constant frequency and a variable path as opposed to a resonating column in which the path length is fixed and the frequency variable.<sup>3</sup>

When an experimental determination of the speed of sound in helium gas as a function of pressure at a constant temperature has been made, the data can be treated to yield values of absolute temperature by means of eq (1).

$$W^2 = (C_p/C_v)_{p=0} R_M T / M_{\text{He}} (1 + \alpha p + \beta p^2 + \dots) \quad (1)$$

where  $W$  is the speed of sound in helium gas;  $(C_p/C_v)_{p=0} = 5/3$ ;  $R_M = 8.314 \times 10^7$  (erg/°K mole);

$M_{\text{He}} = 4.0026$ ;  $p$  is the pressure;  $\alpha = 1/(RT)[2B + 4/3(T)(dB/dT) + 4/15(T^2)(d^2B/dT^2)]$ ;  $B$  is the second virial coefficient; and  $T$ , the absolute temperature.

In practice, values of the speed,  $W$ , are experimentally determined at pressures sufficiently low that the plot of  $W$  versus  $p$  is linear and can be extrapolated to zero pressure; the intercept is then the value of the speed of sound for an ideal gas, and eq (1) reduces to

$$W_0^2 = (C_p/C_v)_{p=0} R_M T / M_{\text{He}}$$

where  $W_0$  is the speed intercept at  $p=0$ . It is to be noted that the acoustical temperature determination eliminates troublesome corrections that are involved in gas thermometry, i.e., dead space corrections, gas adsorption and precise volume changes and pressure determinations.

One of the most critical parts of the thermometer is the portion of the apparatus which contains the sonically excited helium gas. This is at the temperature to be maintained constant and determined. To aid in accomplishing this, several secondary thermometers of high sensitivity (germanium resistors) were in intimate thermal contact with the region. One resistor served as a sensor for an automatic heater controlling unit while two other resistors indicated how well a constant temperature was being maintained and also served as secondary thermometers which were calibrated by the acoustical thermometer. All of this portion of the apparatus was suitably thermally insulated from the surrounding liquid helium or liquid hydrogen bath so that it could be isothermally floated in the temperature region of interest. While this portion of the acoustical thermometer was maintained constant in temperature the speed of sound in the helium 4 gas was measured as a function of pressure. (This is referred to as an isotherm in our work.)

During the hours that are spent on any given isotherm, germanium resistance values are systematically measured. In general five to seven

\*This paper was presented at the 1964 meeting of the Thermometry Advisory Committee of the International Committee of Weights and Measures.

<sup>1</sup> Figures in brackets indicate the literature references at the end of this paper.

<sup>2</sup> The NBS acoustical interferometer has been cursorily described in the literature [5, 6] the details will appear later.

<sup>3</sup> Measurement of the sound speed in helium gas yielding absolute temperature determinations have also been conducted with the resonating tube. Some results have been reported by De Laet [7] and by Brodsky, Kremlevsky, and Savateev [8].

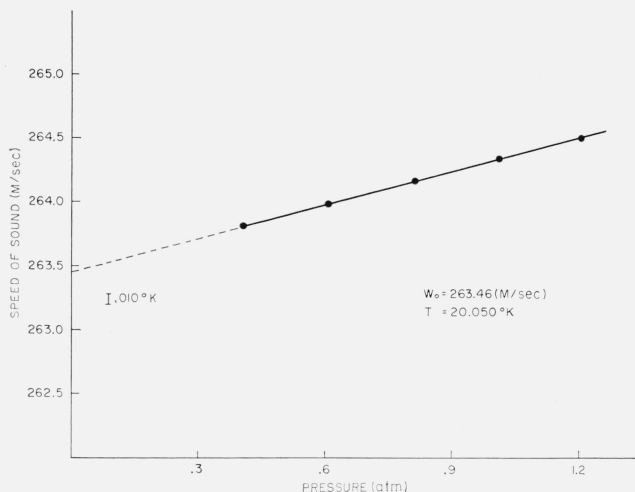


FIGURE 1. 20.050 °K Isotherm.

The dashed line is the extrapolation of the isotherm to zero pressure.

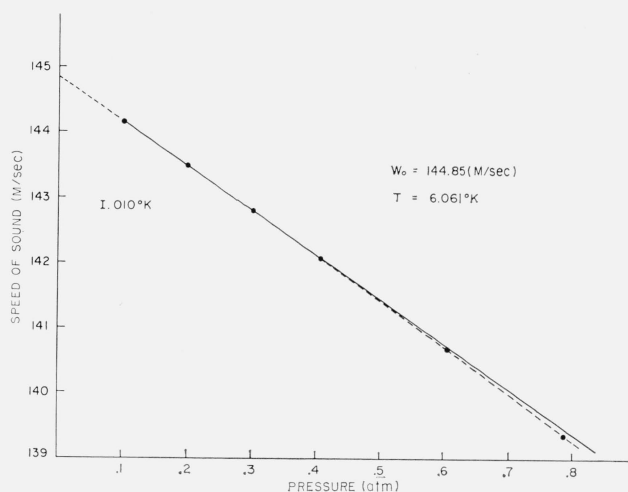


FIGURE 2. 6.061 °K Isotherm.

At the lowest pressures the dashed line depicts the extrapolation to zero pressure. At the highest pressure, the dashed line indicates departure of the isotherm from a linear representation (the solid line).

pressure-speed points were measured to establish each isotherm. Figures 1 and 2, typical of the determined isotherms, indicate how the isotherm is extrapolated to zero pressure; the intercept affords a simple calculation of the isotherm temperature.

For the pressures employed in the temperature range of interest, all of the isotherms are linear within the limits of experimental reproducibility. At sufficiently large pressures, however, departures from linearity are to be expected. For example, in figure 2 the measurements indicate that the isotherm has noticeably departed from linearity at 0.6 atm and above, whereas in figure 1 a linear representation of the isotherm up to 1.2 atm appears satisfactory. We have generally observed that experimental reproducibility of points on an isotherm is  $\pm 0.002$  °K. If one conducts measurements at pressures sufficiently low that the isotherm can be represented by a straight line, an important check on the consistency of the isotherms is afforded by the smoothness of the plot of isotherm slopes as a function of the determined temperatures. The slopes naturally are related to the virial coefficients and will permit their determination.

Isotherms have been determined every degree from 5 to 20 °K and accordingly at each temperature several germanium resistors were calibrated. Because it was desirable to compare the acoustical thermometer scale with other existing scales in regions of overlap, several germanium resistors were calibrated by Riddle's group against the NBS (1955) provisional scale which is based on earlier gas thermometry<sup>4</sup> and preserved by a group of platinum resistors.

Every germanium resistor which was used has a history of at least one year in our laboratory and some have demonstrated a reproducible 4.2 °K calibration (against the He<sup>4</sup> vapor pressure scale,  $T_{58}$ ) within 0.001 °K even when subjected to 100 thermal cyclings between room temperature and 4.2 °K. Of the two resistors which were calibrated against the NBS (1955) provisional scale, one was calibrated in May 1963 and the other in June 1964. Both resistors were compared to the acoustical thermometer scale in June 1964 by being mounted in the acoustical thermometer and brought to the acoustically determined temperatures at which the instrument germanium resistors had been calibrated. This has afforded a comparison of acoustically determined temperatures with those associated with the NBS (1955) provisional scale between 10 and 20 °K. And, since the NBS (1955) provisional scale has recently been compared with other scales, the acoustically determined temperatures can be related to these also. This has been done in figure 3.

Most of figure 3 has originated from the National Physical Laboratory and has been confirmed by PRMI.<sup>5</sup> It is to be noted that there is an excellent agreement between the acoustically determined temperature and both the NPL and NBS scale from 12 to 20 °K. Indeed, even the departure of the NPL scale from the NBS scale in the vicinity of 14 °K appears to be strongly supported. Unfortunately

<sup>4</sup> The NBS (1955) provisional scale was obtained by subtracting 0.010 °K from the NBS (1939) scale [9].

<sup>5</sup> The general plot was included in a paper submitted by C. R. Barber to the Thermometry Advisory Committee of the International Committee of Weights and Measures (Sept. 1964). At the same meeting a paper submitted by M. P. Orlova, D. I. Sharevskaja, and D. N. Astrov confirmed in detail the results of C. R. Barber.

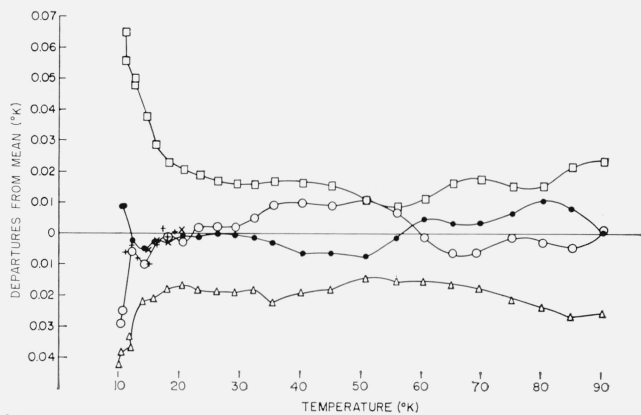


FIGURE 3. Values of temperature determined with the acoustical thermometer are compared with temperature scales from Pennsylvania State University, Physical-technical Radio-technical Measurements Institute, The National Physical Laboratory, and the NBS (1955) provisional scale.

△, PSU; □, PRMI; ●, NBS; ○, NPL; ×, +, acoustical thermometer.

it has not been convenient to compare our temperatures with the NBS scale at 10 °K. We are not in a position at present to state the accuracy of our temperature determinations but we have stated the experimental reproducibility of our isotherm measurements previously in this paper.

Our experience thus far, although it is limited, cautions us to doubt the accuracy of published hydrogen vapor-pressure scales. Our preliminary measurements indicate that the "accepted" equilibrium hydrogen boiling point may be 20 mdeg lower than its thermodynamic temperature; this possible inaccuracy may also exist throughout the

hydrogen vapor pressure scale to some extent. Quite consonant with this conclusion is the possibility of error in the  $T_{55} \text{He}^4$  vapor scale also. Preliminary measurements again indicate that the  $\text{He}^4$  boiling point may be 0.006 °K too low; and that  $\text{He}^4$  vapor pressure scale temperatures near 2 °K may be 0.003 °K low also.

It is expected that the values of acoustically determined temperatures described in this paper will result in a provisional scale which will be used by the National Bureau of Standards principally for calibrations of germanium resistance thermometers from 5 to 20 °K.

## References

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(Paper 69A4-358)

## Publications of the National Bureau of Standards\*

### Selected Abstracts

**International comparison of atomic frequency standards via VLF radio signals**, A. H. Morgan, E. L. Crow, and B. E. Blair, *Radio Sci. J. Res. NBS/USNC-URSI*, Vol. 69D, No. 7, 905–914 (July 1965).

A study was made of data obtained over an 18-month period (July 1961 to December 1962, inclusive) on the comparison of atomic frequency standards located in seven laboratories in the United States, Europe, and Canada, using the VLF signals of GBR (16 kc/s), Rugby, England and NBA (18 kc/s), Balboa, Canal Zone. Each laboratory observes the accumulated difference in phase over a 24-hr period (the same for all laboratories, or nearly so) between its own standard (either laboratory or commercially constructed) and the received VLF signal. A statistical analysis was designed to separate the observations at each laboratory into three components: (a) long-term mean differences among the atomic standards; (b) estimates of the standard deviations,  $\hat{\alpha}_i$ , at each receiving station; and (c) estimates of the transmitter standard deviations,  $\hat{\tau}$ . Each  $\hat{\alpha}_i$  includes receiver fluctuations, propagation effects peculiar to the path, and measurement uncertainties;  $\hat{\tau}$  includes the transmitter fluctuations and propagation effects common to all paths.

The study shows that  $\hat{\alpha}_i$  at each receiver varied from a low of  $0.39 \times 10^{-10}$  units of fractional frequency (that is, 0.39 parts in  $10^{-10}$  (GBR data) at LSRH to a high of  $1.97 \times 10^{-10}$  (GBR data) at NRC with an average for all stations of  $1.01 \times 10^{-10}$  measured against GBR and  $0.99 \times 10^{-10}$  when measured against NBA. Also, the average  $\hat{\tau}$  for GBR is  $1.26 \times 10^{-10}$  and for NBA is  $0.68 \times 10^{-10}$ . Finally, it is shown that: (1) The means of the frequencies of the seven individual atomic standards laboratories agreed with the grand mean of these seven standards to within  $\pm 2$  parts in  $10^{10}$  for the 18-month period, and (2) The laboratory-type standards agreed with their grand mean to within  $\pm 1$  part in  $10^{10}$ .

**Control of WWV and WWVH standard frequency broadcasts by VLF and LF signals**, B. E. Blair and A. H. Morgan, *Radio Sci. J. Res. NBS/USNC-URSI*, Vol. 69D, No. 7, 915–920 (July 1965).

Since 1961 the NBS VLF and LF signals have improved the calibration and frequency control of the WWV (Maryland) HF broadcasts. Similarly, better control of the WWVH (Hawaii) HF broadcasts was achieved in early 1963 by monitoring the NBS VLF broadcasts in terms of the WWVH control oscillator. In mid 1963 WWVL (20 kc/s) and WWVB (60 kc/s) were relocated from two sites near Boulder, Colo., to a single site near Fort Collins, Colo., and the transmitter power for both broadcasts was increased several fold. These higher powered broadcasts resulted in more precise control of both HF broadcasts. Through the VLF and LF signals the 24-hr average frequency values of WWV are related to the United States Frequency Standard (USFS) within a few parts in  $10^{11}$ .

This paper describes the NBS low-frequency broadcasts, the method of using them to control and calibrate the HF broadcasts, and gives an analysis of the precision of frequency control obtained at WWV over a 21-month period. An appendix discusses the short-term phase stabilities and diurnal phase shifts observed in the low-frequency signals at WWV and WWVH, and examines the accuracy-limiting effects of propagation path characteristics and background noise levels in such received signals.

**Measurements of the total electron content and the equivalent slab thickness of the midlatitude ionosphere**, R. V. Bhonsle, A. V. da Rosa, and O. K. Garriott, *Radio Sci. J. Res. NBS/USNC-URSI*, Vol. 69D, No. 7, 929–937 (July

1965). The total electron content  $N_T$  and the equivalent slab thickness  $\tau$  of the midlatitude ionosphere are determined from differential Doppler measurements on the radio transmissions from the Transit 4A satellite and the ionosonde data near Washington, D.C., and Ottawa. The trends of diurnal, seasonal, and sunspot cycle variations of  $N_T$  and  $\tau$  at midday are described. It is found that in 1962 both  $N_T$  and  $\tau$  were considerably decreased in magnitude as compared to the corresponding values near the peak of the sunspot cycle. The inferred mean electron-ion temperature is found to be generally in excess of the neutral gas temperature. The ratio  $T_e/T_n$  in the daytime is estimated to be 1.8 in summer and about 1.1 to 1.2 in winter, which may reflect corresponding changes in the ratio  $Q/N_e^2$ , where  $Q$  is the heat input to the electrons and  $N_e$  is the electron density. The relationship between  $\tau$  and  $K_p$  appears to be rather ambiguous in contrast with the positive correlation between the neutral gas temperature and  $K_p$ .

**Calibration of liquid-in-glass thermometers**, J. F. Swindells, *NBS Mono. 90* (Feb. 12, 1965), 25 cents. Supersedes NBS Cir. 600.

This Monograph, which supersedes Circular 600, contains information of general interest to both manufacturers and users of liquid-in-glass thermometers, as well as those who wish to calibrate thermometers or submit them to the National Bureau of Standards for calibration. Instructions are provided for applicants requesting calibration services, and the techniques and equipment used in the calibration procedures are described. Important elements of thermometer design are discussed, and factors affecting the use of common types of liquid-in-glass thermometers are included together with tables of tolerances and reasonably attainable accuracies. The calculation of corrections for the temperature of the emergent stem is given in detail for various types of thermometers and conditions of use.

**Standard cells. Their construction, maintenance, and characteristics**, W. J. Hamer, *NBS Mono. 84* (Jan. 15, 1965), 35 cents.

This Monograph contains information on the construction, maintenance, and characteristics of standard cells. The effects of temperature, pressure, electric current, light, shock, and vibration on standard cells are discussed. A history of the realization and maintenance of the unit of electromotive force is also included. A record of international comparisons of the unit of electromotive force is presented as well as information in the constancy of the National Reference Group of Standard Cells.

**Standard Reference Materials: Sources of information**, J. L. Hague, T. W. Mears, and R. E. Michaelis, *NBS Misc. Publ. 260-4* (Feb. 1965), 20 cents.

This annotated listing of sources of Standard Reference Materials is prepared with references to all types of materials used to standardize analytical, physico-chemical and engineering methods. The range of Standard Reference Materials included runs from high-purity substances and carefully analyzed metals, alloys and rocks to materials of indefinitely-known composition for standardizing a single phenomenon.

**Report of the 49th National Conference on Weights and Measures 1964**, *NBS Misc. Publ. 263*, (Feb. 1, 1965), \$1.00. A report of the proceedings of the fourth-ninth National Conference on Weights and Measures, held in Washington, D.C., June 15–19, 1963, and attended by State, county, and city weights and measures officials.

**The Joule-Thomson process in cryogenic refrigeration systems**, J. W. Dean and D. C. Mann, *NBS Tech Note 227* (Feb. 14, 1965), 30 cents.

A comprehensive analysis of the Joule-Thomson process as applied to cryogenic refrigeration systems is presented. The descriptions of the process already in the literature are usually for specific applications. In contrast, performance characteristics are presented here for helium, para-hydrogen, and nitrogen operations over a large range of process parameters.

**Nonlinear ambipolar diffusion of an isothermal plasma across a magnetic field**, E. R. Mosburg and K. B. Persson, *Phys. Fluids* **7**, 1829-1833 (Nov. 1964).

Solutions are presented of the first two moment equations, including non-linear terms, for the ambipolar diffusion of an isothermal plasma across a magnetic field. The two geometries considered are the plane parallel case and the infinite cylinder with axial symmetry. The Bohm criterion is automatically satisfied by the solutions. It is shown that the singularity in the space derivative of the ambipolar drift velocity at the plasma boundary cannot be removed by an axial magnetic field of any strength. Thus the plasma drift velocity and the plasma density remain monotonic functions of the position coordinate. It is also shown, under the assumptions of this theory, that the ambipolar space charge field is always directed outward and does not reverse direction in this isothermal approximation even for extremely high magnetic fields. One is forced to conclude that a realistic theory of ambipolar diffusion requires the consideration of the thermal gradients within the plasma.

**Interacting of maxima in the absorption of soft x-ray**, J. W. Cooper, *Phys. Rev. Letters* **13**, No. 25, 762-764 (Dec. 21, 1964). The interpretation of recently observed maxima in photoelectric cross sections in the soft x-ray region is given in terms of a one-electron central field model. The observations, which represent a departure from the usual behavior of x-ray absorption cross sections, is shown to be consistent with the one-electron central field description.

**Natural variations in the abundance ratio and the atomic weight of copper**, W. R. Shields, S. S. Goldich, E. L. Garner, and T. J. Murphy, *J. Geophys. Res.* **70**, No. 2, 479-491 (Jan. 15, 1965).

The absolute ratio  $\text{Cu}^{63}/\text{Cu}^{65}$  was determined for 106 samples that include a variety of copper minerals. Relative to a reference copper sample with previously determined absolute ratio of  $2.2440 \pm 0.0021$ , variations range from  $-9.0$  to  $+3.3$  per mil. No significant variations were found for chalcopyrite, tetrahedrite, enargite, or in the Canyon Diablo and Bruderheim meteorites. Some samples of bornite and of chalcocite exhibit variations with enrichments in either  $\text{Cu}^{63}$  or in  $\text{Cu}^{65}$ . Secondary oxides of copper show significant enrichment only in the heavy isotope. The relative variations previously reported by Walker, Cuttitta, and Senftle for samples from the Cougar mine, Colorado, are confirmed. A mean value of 2.2431 for 82 mineral samples probably is unduly weighted with the rarer secondary minerals that are enriched in  $\text{Cu}^{65}$ . The ratio  $\text{Cu}^{63}/\text{Cu}^{65}$  for bulk or commercially processed copper is very near to the value of 2.2440, and the atomic weight of such copper is  $63.5455 \pm 0.0010$ . The causes of the natural variations in copper abundance ratios are not known.

**Optical heterodyne detection of the forward stimulated Brillouin scattering**, D. A. Jennings and H. Takuman, *Appl. Phys. Letters* **5**, 241-242 (Dec. 1964).

The small frequency shift associated with the small angle forward Brillouin scattering in carbon disulfide when excited by the Q-switched ruby laser has been measured by using an optical heterodyne technique. The frequency shift was measured to be 123 Mc/sec for an off-axis angle of 0.0433 rad. The velocity of sound at 123 Mc/sec in carbon disulfide was calculated to be  $1223 \pm 24$  m/sec from these measurements.

**The calibration of the National Bureau of Standards' tritiated-toluene standard of radioactivity**, S. B. Garfinkel, W. B. Mann, R. W. Medlock, and O. Yura, *Intern. J. Appl. Radiation Isotopes* **16**, 27-33 (1965).

The difficulties encountered, and their solution, when calibrating a radioactivity standard of tritiated toluene by com-

parison with the NBS tritiated water standard by means of liquid scintillation counting, are described. Leaks in the seals of commercial vials, giving rise to uncontrolled oxygen quenching, were eliminated by modifying the seals. White plastic caps gave higher count rates than black plastic caps. A new and highly precise method of dilution was used. The ratio of the activities of the two standards was determined with a standard error of less than 0.1 percent.

**Conductance of glass immersed in molten salts**, K. H. Stern, *J. Electrochem. Soc.* **112**, No. 2, 208-210 (Feb. 1965)

The electrical conductivity of high  $\text{SiO}_2$  glass was measured when immersed in a number of molten salts and salt mixtures between 800 and 900° C. Sodium and lithium ions diffuse into the glass, both from their own chlorides and from low concentrations in KCl. The glass comes to equilibrium with each melt composition, the time of equilibration depending on the particular ions in the melt. The activation energy of sodium and lithium ion conduction in glass is 75-84kj (18-20 kcal), with potassium it is variable between 105 (25 kcal) and 167 (40 kcal). The conductance method is not sufficiently precise to detect silver and cuprous ion diffusion into glass.

**Magnetic properties of ilmenite-hematite solid solutions**, C. F. Jefferson and R. G. West, *J. Am. Ceram. Soc.* **47**, No. 11 544-548 (Nov. 1964).

The magnetic and dielectric properties of some ilmenite-hematite solid solutions are reported. These properties are found to resemble those of the ferrites. Compositions were prepared that possess high electrical resistivities and low dielectric losses. The introduction of manganese into the system  $(1-x) \text{Ni}_{1-y} \text{Mn}_y \text{TiO}_3 + x \text{Fe}_2\text{O}_3$  increases the room temperature magnetic moments and decreases the resistivities.

**Properties of normal and para hydrogen**, R. B. Stewart and H. M. Roger, *Book Technology and Uses of Liquid Hydrogen*, ed. R. B. Scott, W. H. Denton, and C. M. Nichols, ch. 11, 379-404 (Pergamon Press Inc., New York, N.Y., 1964).

The P-V-T, thermodynamic and transport properties of normal and para hydrogen for low temperatures are summarized in tables and graphs from selected references.

**Thermodynamics of hydrogen solubility in cryogenic solvents at high pressures**, M. Orentlicher and J. M. Prausnitz *Book, Chem. Eng. Sci.* **19**, 775-782 (1964).

Solubility data for hydrogen in liquids at low temperature and high pressure have been reduced by a thermodynamic relation similar to the Krichevsky-Kasarnovsky equation but allowing for the variation of activity coefficient with hydrogen concentration. The parameters appearing in this relation have been partially correlated on the basis of a very simple solution model. The results show that under comparable conditions the solubility of hydrogen in simple inorganic solvents (argon, nitrogen, carbon monoxide) is considerably larger than that in light hydrocarbons (ethane, ethylene, propane, propylene) with methane falling in between these groups. Some possible explanations are suggested.

**Surface integral form for three-body collision in the Boltzmann equation**, M. S. Green, *Phys. Rev.* **136**, No. 4A, A905-A910 (Nov. 16, 1964).

A new form is given for the triple collision term in the generalized Boltzmann equation which is more similar to the well-known binary collision expression than those given heretofore. The form involved is a surface integral over a five-collision parameter space which is the generalization of the two-dimensional collision parameter space for binary collisions. For "soft" repulsive interactions, the expression involves both the asymptotic properties of three-body collisions before and after the collision and the dynamics of binary collisions during the collision process. For hard spheres, the expression involves only the asymptotic properties of ternary and binary collisions.

**Food for tomorrow's billions**, A. T. McPherson, *Proc. forum "Food in the Future: Concepts for Planning,"* Chicago, Ill., Oct. 8-9, 1964, pp. 51-73 (Dairy and Food Industries Supply Assoc., 1964).

The problem of population and food is as old as the human race. The discovery of agriculture about 9,000 years ago made possible an enormous increase in the food supply and a corresponding increase in population. The world population has been increasing at an accelerating rate since 1650. Today over half of the people have a diet insufficient in quantity and inadequate in quality and the explosive increase in population is accentuating the shortage.

Direct synthesis of food is proposed as a means of quickly supplementing agricultural production of protein and fat which are especially needed in Asia and the Far East. The feasibility of synthesis is demonstrated by the successful production of nearly all non-food agricultural products, and the current manufacture of vitamins and amino acids for use both in animal feeding and for human consumption. The use of petroleum as a raw material for synthesis would require only a fraction of the quantity now used as fuel. The present world situation calls for a major new source of food at the earliest possible time. The early development of large scale synthesis affords a feasible means of meeting this need.

**Stress-induced Martensitic transformations in 18Cr-8Ni steel.** R. P. Reed and C. J. Gutner, *Trans. Met. Soc. AIME* **230**, 1713-1720 (Dec. 1964).

A commercial 18Cr-8Ni iron alloy (AISI 304L) was examined in tension at 300, 76, 20, and 4° K. Continuous stress-strain recordings were made, x-ray analyses at periodic stress (strain) intervals were obtained, and magnetic measurements were taken. From this data the percentage of martensitic products (BCC( $\alpha$ ) and HCP( $\epsilon$ )) were computed as a function of stress (strain).

It was found that up to 15%  $\epsilon$  phase forms at low temperatures. The amount of  $\epsilon$  formed increases to about 5% strain, then decreases. This decrease indicates the additional transformation of  $\epsilon$  to  $\alpha'$ . The total amount of  $\epsilon$  and  $\alpha'$  was suppressed at constant stress (strain) at 4° K as compared to 76° K. It is proposed that the suppression of  $\epsilon$  and  $\alpha'$  is associated with the decreased mobility of extended dislocations at very low temperatures. The yield strength decreased as the temperature was depressed below room temperature and then increased rapidly near 4° K.

**High resolution, low energy electron spectrometer.** J. A. Simpson, *Rev. Sci. Instr.* **35**, No. 12, 1698-1704 (Dec. 1964). An electron spectrograph consisting of an electron source, an electron monochromator, a gas cell, and an electron energy analyzer is described. The electron energy spread from the monochromator as seen by the analyzer is 0.005 eV at 3.35 eV primary energy. It is shown that space charge within the beam requires operation of the energy selectors at the lowest possible energy if high current together with high resolution are required.

**Electron-impact studies of aromatic hydrocarbons. III. Azulene and naphthalene.** R. J. Van Brunt and M. E. Wacks, *J. Chem. Phys.* **41**, No. 10, 3195-3199 (Nov. 15, 1964).

The ionization-dissociation processes in azulene and naphthalene were studied. The appearance potentials of the major ions in their mass spectra were determined. The observed ionization energies of naphthalene (8.26 eV) and azulene (7.72 eV) and the heats of formation of these compounds provided an energetic scheme consistent with the measured appearance potentials of the secondary ions and the assumption of ionic intermediates common to both compounds. The occurrence of these common intermediate ions which lead to the observed fragmentation in these compounds was also demonstrated by the similarity of the mass spectra of these two compounds. Additional evidence was provided by observations made of the metastable ion transitions found in their mass spectra.

**Electron-impact studies of aromatic hydrocarbons. II. Naphthalene, chrysene, triphenylene, and pyrene.** M. E. Wacks, *J. Chem. Phys.* **41**, No. 6, 1661-1666 (Sept. 15, 1964). The systematic survey of ionization-dissociation processes of fused-ring aromatic compounds initiated previously is continued. Mass spectra and appearance potentials of the singly and doubly charged molecule ions are reported. The observed ionization energies of naphthalene (6.95 eV),

naphthalene (7.53 eV), chrysene (8.01 eV), triphenylene (8.19 eV), and pyrene (7.72 eV) are compared with available spectroscopic data, with values obtained from molecular orbital calculations, with the available empirical and semi-empirical methods, and with other electron impact data.

**Formation of NF from NF<sub>2</sub> by photolysis.** D. E. Mann and J. J. Comford, *Spectrochim. Acta* **21**, 197-198 (*Perгамon Press Ltd., Northern Ireland, 1965*).

The NF radical has been produced along with NF<sub>3</sub> by photolysis of NF<sub>2</sub> isolated in a solid argon matrix at 4° K. The results indicate that the F atoms formed by the photodecomposition NF<sub>2</sub>  $\xrightarrow{h\nu}$  NF + F are able to diffuse easily through the matrix even at 4° K, whereas the other principal species present, NF and NF<sub>2</sub>, are comparatively immobile under these conditions.

**Spectral properties of plants.** D. M. Gates, H. J. Keegan, J. C. Schleiter, and V. R. Weidner, *Appl. Opt.* **4**, No. 1, 11-20 (Jan. 1965).

The spectral photometric properties of plant leaves and stems have been obtained for ultraviolet, visible, and infrared frequencies. The spectral reflectance, transmittance, and absorptance for certain plants is given. The mechanism by which light and radiation interact with a leaf is discussed, including the presence of plant pigments. Examples are given concerning the amount of absorbed solar radiation for clear sky and overcast conditions. The spectral properties of desert plants are compared with those of more mesic plants. The evolution of the spectral properties of plant leaves during the early growing season is given as well as the colorimetric behavior during the autumn.

### Other NBS Publications

**Radio Sci. J. Res. NBS/USNC-URSI, Vol. 69D, No. 6 (June 1965), \$1.00.**

Cyclotron harmonic waves in warm plasma. F. W. Crawford. Propagation of waves across a magnetoplasma-vacuum boundary. R. L. Gallawa.

Phase velocities and attenuation distances in the ionosphere. D. R. Croley, Jr., and B. S. Tanenbaum.

Ionospheric effects of electrostatic fields generated in the outer magnetosphere. G. C. Reid.

An experimental study of plasma sheath effects on antennas. G. Tyras, P. C. Bargeliotis, J. M. Hamm, and R. R. Schell.

An approach to improve re-entry communications by suitable orientations of antenna and static magnetic field. S. N. Samaddar.

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Angles in focus. D. Atlas.

An investigation of clear air stratification with radar and elevated instruments. D. R. Hay and K. Naito.

On inferring the refractive-index structure of the troposphere from electromagnetic scattering experiments. P. L. Smith, Jr.

The biexponential nature of tropospheric gaseous absorption of radio waves. E. J. Dutton and B. R. Bean.

Complete scattering parameters of polydispersed hydrometeor in the  $\lambda$  0.1 to  $\lambda$  10 cm range. D. Deirmendjian.

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International comparison of atomic frequency standards via VLF radio signals. A. H. Morgan, E. L. Crow, B. E. Blair. (See above abstracts.)

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Measurements of the total electron content and the equiv-

- alent slab thickness of the midlatitude ionosphere. R. V. Bhonsle, A. V. da Rosa, and O. K. Garriott. (See above abstracts.)
- D-region absorption at 10 and 15 Mc/s during the total solar eclipse of July 20, 1963. G. M. Lurfald, J. K. Hargreaves, and J. M. Watts.
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- Electromagnetic properties of a plasma covered antenna. D. J. Jacavano.
- Influence of an inhomogeneous ground on the propagation of VLF radio waves in the earth-ionosphere waveguide. J. R. Wait.
- Aspects of the terrestrial ELF noise spectrum when near the source or its antipode. L. G. Abraham, Jr.
- Analysis of linear arrays focused in the Fresnel region. P. P. Lombardini, R. Doviak, and J. Goldhirsh.
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