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Table and Mollier Chart for Ammonia Below −60° F

by Cyril H. Meyers

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Table and Mollier Chart for Ammonia Below —60° F

By **Cyril H. Meyers**

Abstract

This paper contains a table of thermodynamic properties of saturated ammonia vapor and liquid below −60° F, and a Mollier chart for saturated and for super heated ammonia vapor covering the pressure range 0.8 to 5 lb/in.^{2} These data are based on the same equations and are expressed in the same units as those used in National Bureau of Standards Circular C142. The table and Mollier chart are extensions of those given in C142 to lower temperatures and pressures, terminating at the triple point of ammonia (−107.86° F, 0.878 lb/in ^{2}).

Extensive tables and a Mollier chart of thermodynamic properties of ammonia were published in 1923 in Bureau Circular C142. The pressure range, 5 to 300 lb/in.^{2}, covered in that publication was adequate for engineering requirements at that time, but the more recent application of ammonia in refrigeration at temperatures below −60° F has resulted in a need for an extension of the data to lower pressures.

Complete recalculation of the properties of ammonia was not considered necessary because (1) the difference between the new experimental data [1] and the calculated values was not large enough to be important in engineering problems, (2) the international steam table Btu recently adopted, differs by slightly less than 0.1 percent from the Btu defined in C142, (3) the necessity for using the obsolete figure 459.58° R in place of the more recent value 459.69° R to maintain internal consistency in calculations causes no appreciable error.

The data in the present extension to the triple point of ammonia (−107.86° F, 0.878 lb/in.^{2}) are based on the same set of empirical equations given in C142, which are consistent with exact thermodynamic relations. The numerical values therefore are expressed in the same units and are entirely consistent with the data in C142. Such consistency is especially important, since many practical applications will involve differences in values taken from the two publications.

Only the properties of the saturated fluid have been tabulated. These are presented in table 1, which is similar in form to table 1 in C142. In computing the values in the table from the empirical equations, all calculations were carried one or two digits beyond the number to be retained in the table, and the values were checked by differences. As a consequence of the rounding-off process, certain values of the latent heat may differ by one in the last place from the relation L-H=h.

In consideration of the large size of tables for superheated vapor and of the fact that the data can be represented on a chart with an accuracy nearly equal to the primary data, the properties of the super-

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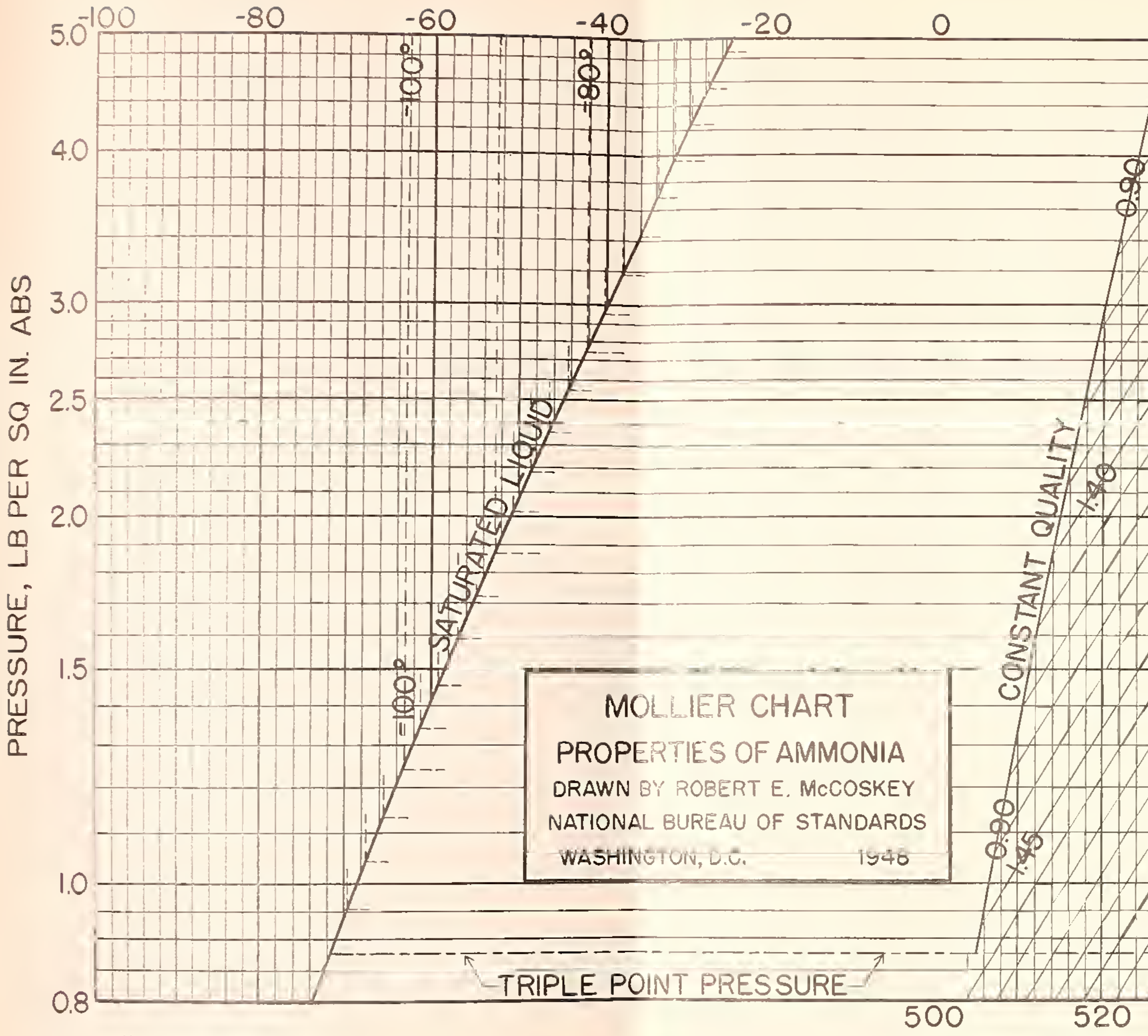
[1] Roy Overstreet and W. F. Ciauque, J. Am. Chem. Soc. **59**, 254, (1937).

TABLE 1. *Saturated ammonia temperature table*

Temperature *t*	Pressure		Volume vapor, *V*	Density vapor 1/*V*	Heat content		Latent heat, *L*	Entropy		Temperature, *t*
	Absolute, *p*	Gage, *gp*			Liquid, *h*	Vapor, *H*		Liquid, *s*	Vapor, *S*	
° *F*	*lb/in.*^{2}	[a] *in.*Hg	*ft*^{3}*/lb*	*lb/ft*^{3}	*Btu/lb*	*Btu/lb*	*Btu/lb*	*Btu/lb° F*	*Btu/lb° F*	° *F*
−107.86	0.878	28.1	251.3	0.00398	−71.6	569.0	640.6	−0.1859	1.6354	−107.86
−107	.912	28.1	242.4	.00413	−70.6	569.4	640.0	−.1833	1.6320	−107
−106	.954	28.0	232.5	.00430	−69.6	569.8	639.4	−.1803	1.6281	−106
−105	0.996	27.9	223.2	.00448	−68.5	570.3	638.8	−.1774	1.6243	−105
−104	1.041	27.8	214.2	.00467	−67.5	570.7	638.2	−.1744	1.6205	−104
−103	1.087	27.7	205.7	.00486	−66.4	571.2	637.6	−.1714	1.6167	−103
−102	1.135	27.6	197.6	.00506	−65.4	571.6	637.0	−.1685	1.6129	−102
−101	1.184	27.5	189.8	.00527	−64.3	572.1	636.4	−.1655	1.6092	−101
−100	1.24	27.4	182.4	.00548	−63.3	572.5	635.8	−.1626	1.6055	−100
−99	1.29	27.3	175.3	.00571	−62.2	572.9	635.2	−.1597	1.6018	−99
−98	1.34	27.2	168.5	.00593	−61.2	573.4	634.6	−.1568	1.5982	−98
−97	1.40	27.1	162.1	.00617	−60.1	573.8	633.9	−.1539	1.5945	−97
−96	1.46	26.9	155.9	.00641	−59.1	574.3	633.3	−.1510	1.5910	−96
−95	1.52	26.8	150.0	.00667	−58.0	574.7	632.7	−.1481	1.5874	−95
−94	1.59	26.7	144.3	.00693	−57.0	575.1	632.1	−.1452	1.5838	−94
−93	1.65	26.6	138.9	.00720	−55.9	575.6	631.5	−.1423	1.5803	−93
−92	1.72	26.4	133.8	.00747	−54.9	576.0	630.9	−.1395	1.5768	−92
−91	1.79	26.3	128.9	.00776	−53.8	576.5	630.3	−.1366	1.5734	−91
−90	1.86	26.1	124.1	.00806	−52.8	576.9	629.7	−.1338	1.5699	−90
−89	1.94	26.0	119.6	.00836	−51.7	577.3	629.0	−.1309	1.5665	−89
−88	2.02	25.8	115.3	.00868	−50.7	577.8	628.4	−.1281	1.5631	−88
−87	2.10	25.6	111.1	.00900	−49.6	578.2	627.8	−.1253	1.5597	−87
−86	2.18	25.5	107.1	.00933	−48.6	578.6	627.2	−.1225	1.5564	−86
−85	2.27	25.3	103.33	.00968	−47.5	579.1	626.6	−.1197	1.5531	−85
−84	2.35	25.1	99.68	.01003	−46.5	579.5	625.9	−.1169	1.5498	−84
−83	2.45	24.9	96.17	.01040	−45.4	579.9	625.3	−.1141	1.5465	−83
−82	2.54	24.7	92.81	.01077	−44.4	580.4	624.7	−.1113	1.5432	−82
−81	2.64	24.5	89.59	.01116	−43.3	580.8	624.1	−.1085	1.5400	−81
−80	2.74	24.3	86.50	.01156	−42.2	581.2	623.5	−.1057	1.5368	−80
−79	2.84	24.1	83.54	.01197	−41.2	581.6	622.8	−.1030	1.5336	−79
−78	2.95	23.9	80.69	.01239	−40.1	582.1	622.2	−.1002	1.5304	−78
−77	3.06	23.7	77.96	.01283	−39.1	582.5	621.6	−.0975	1.5273	−77
−76	3.18	23.5	75.33	.01327	−38.0	582.9	621.0	−.0947	1.5242	−76
−75	3.29	23.2	72.81	.01373	−37.0	583.3	620.3	−.0920	1.5211	−75
−74	3.42	23.0	70.39	.01421	−35.9	583.8	619.7	−.0892	1.5180	−74
−73	3.54	22.7	68.06	.01469	−34.9	584.2	619.1	−.0865	1.5149	−73
−72	3.67	22.4	65.82	.01519	−33.8	584.6	618.4	−.0838	1.5119	−72
−71	3.80	22.2	63.67	.01571	−32.8	585.0	617.8	−.0811	1.5089	−71
−70	3.94	21.9	61.60	.01623	−31.7	585.5	617.2	−.0784	1.5059	−70
−69	4.08	21.6	59.61	.01678	−30.7	585.9	616.6	−.0757	1.5029	−69
−68	4.23	21.3	57.69	.01733	−29.6	586.3	615.9	−.0730	1.4999	−68
−67	4.38	21.0	55.85	.01791	−28.6	586.7	615.3	−.0703	1.4970	−67
−66	4.53	20.7	54.08	.01849	−27.5	587.1	614.6	−.0676	1.4940	−66
−65	4.69	20.4	52.37	.01910	−26.5	587.5	614.0	−.0650	1.4911	−65
−64	4.85	20.0	50.73	.01971	−25.4	588.0	613.4	−.0623	1.4883	−64
−63	5.02	19.7	49.14	.02035	−24.4	588.4	612.7	−.0596	1.4854	−63
−62	5.19	19.4	47.62	.02100	−23.3	588.8	612.1	−.0570	1.4826	−62
−61	5.37	19.0	46.15	.02167	−22.2	589.2	611.4	−.0543	1.4797	−61
−60	5.55	18.6	44.73	.02235	−21.2	589.6	610.8	−.0517	1.4769	−60

[a] Inches below 1 atmosphere, or (29.92 absolute vapor pressure, in Hg).



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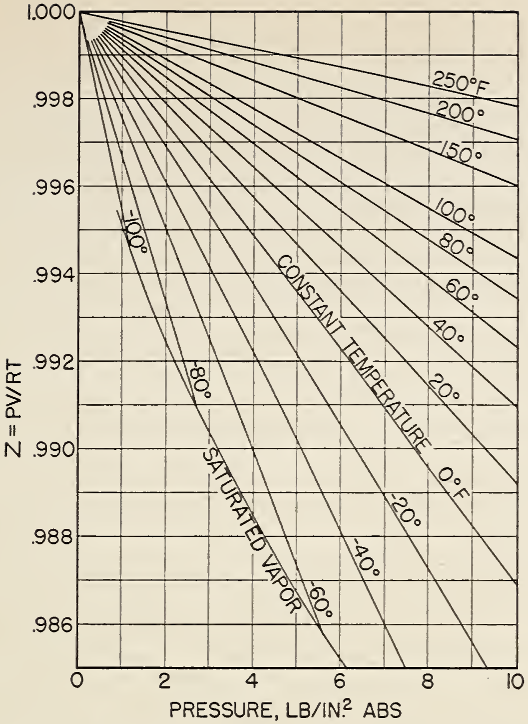

FIGURE 1. *Pressure-volume-temperature relation for ammonia*

heated vapor are presented only in graphical form. The Mollier chart included here represents an extension of a similar chart in C142 to cover the pressure range 0.8 to 5 lb/in^2. Lines of constant volume have been omitted from the present chart in order to make the chart more easily readable.

Figure 1 presents data by which the specific volume of ammonia vapor at temperatures from $-100°$ to $+250°$ F and at pressures below 10 lb/in.^{2} absolute may be readily calculated from values of $Z=pV/RT$ by means of the relation $v=ZRT/p$. With p in pounds per square inch and the relation between the temperature scales used in C142 ($T=459.58+t$°F), the appropriate value of R to give the specific volume in cubic feet per pound is 0.63020. For example, to find the specific volume at $-30°$ F and at 7 lb/in.^{2}, one reads from figure 1, the value of 0.9875 for Z, $T=459.58-30$, and $V=0.9875$ (0.63020) 429.58/7=38.19 cu ft/lb, which is in exact agreement with the value found on page 32 of C142.

The author expresses thanks to Robert E. McCoskey, who drew the chart and assisted with some of the computations. Credit is also due to those who produced Circular C142, in particular to C. S. Cragoe and M. S. VanDusen.

WASHINGTON, May 10, 1948.

U S. GOVERNMENT PRINTING OFFICE: 1948

UNITED STATES DEPARTMENT OF COMMERCE
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MEASUREMENT OF RADIOACTIVE ISOTOPES

National Bureau of Standards Circular 473

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1948

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MEASUREMENT OF RADIOACTIVE ISOTOPES

by Leon F. Curtiss

This manual is intended to accompany radioactive standards and calibrated samples of radioisotopes. It contains a discussion of the principles of measurement of radioisotopes in absolute terms with explanation of units and illustrative examples of precautions that must be taken in measurements to determine disintegration rates. A simple chart for computation of radioactive decay is included.

Introduction

The determination of the number of radioactive atoms in a sample of a radioactive isotope has become a matter of importance as these isotopes have not only become an article of commerce but are also used in biological and medical experiments and even in clinical treatment of diseases. Uniform quantitative results in all laboratories can only be obtained by using procedures that will yield absolute measurements or by the use of uniform standards of comparison that will, under proper conditions of measurement, give the same result whenever the determination is made. The National Bureau of Standards has the responsibility for establishing standards in the various fields of quantitative measurements, such as is represented by the measurement of radioisotopes. It also is interested in making information available so that such standards as it may issue can be used in a way to provide correct and reliable results.

In this situation there are really two factors involved. One is that methods and standards that are correct in principle must be used. The other is that a reasonable degree of accuracy in all steps in the process not only of producing but also of using standards must be attained.

Basic Principles of Measurement of Radioisotopes

What is actually desired in the measurement of a sample of a radioisotope is the number of radioactive atoms present. This determines the strength of the source. There are three basic concepts involved:

1. Total number of radioactive atoms present $=N$.
2. The disintegration constant = decay constant $=\lambda$.
3. The rate of disintegration =“activity” $=\lambda N$.

The actual number of radioactive atoms present is related to the rate at which the atoms are disintegrating at any particular time by the disintegration constant, usually represented by λ. The number of radioactive atoms present is given by the *disintegration rate* divided by λ. This follows from the fundamental law of radioactive decay,

$$\frac{dN}{dt}=-\lambda N,$$

where N is the number of atoms present. The disintegration constant is obtained from the half-value period T by the relation

$$\lambda=\frac{0.693}{T}.$$

(The number 0.693 is an approximate value of $\log_e 2$.)

Therefore, it is apparent that it is necessary to measure the rate of disintegration, that is, the number of atoms disintegrating in unit time, in order to determine the total number of atoms present. This disintegration rate is of course equal to the number of nuclear particles, usually beta particles or positrons, which are emitted per unit time from all atoms which disintegrate within this interval of time. This is true since, in general, one of these particles is emitted for each disintegration which takes place. There are important exceptions to this general rule, which will be discussed later.

The requirement that all disintegration particles must be counted per unit time is by no means simple. The principal difficulty is that these particles are emitted equally in all directions, so that it is practically impossible to devise detecting equipment that will record all of them. If we take the Geiger-Müller beta-ray end-window counter as an example, we find that it has a window through which the beta particles enter. A source is placed in front of this window. The counter can record only that fraction of the particles which pass through it. This will represent probably of the order of 25 percent of the particles actually emitted, from geometrical considerations alone. At least three other factors are present that may distort the results:

1. Absorption of particles in the window,
2. Absorption of particles in the source, and
3. Backward scattering of particles by the support of the source, which will direct some particles through the window that were emitted in some other direction originally.

Factors 1 and 2 reduce the number from the correct value, and 3 increases it.

Conceivably the contribution of all of these factors can be evaluated experimentally for a particular source and a definite arrangement of the apparatus. This not only requires considerable work but must be repeated whenever changes are made in either the source or the apparatus.

Use of Radioactive Standards

Most of the difficulties in making quantitative determinations of radioisotopes can be eliminated if standard sources of the radioisotope under measurement are available. A standard source consists of a preparation of the isotope in a form convenient for use with the detector of radiation, and for which the disintegration rate is known from previous calibration. Assuming that the standard is prepared from the *same* isotope as that to be measured, only three simple precautions are required to secure reliable results: (1) Readings must be made with the standard in the same position as that at which readings are made on the sample, (2) the sample must be uniformly distributed over approximately the same geometrical area as the standard, and (3) the sample must be supported on a layer of material identical with that supporting the standard or at least must produce the same back-scattering effect.

Unfortunately, it is possible to produce standards of relatively few radioisotopes. Obviously, to be useful as a standard, a radioisotope must have a relatively long half-life. On the other hand, many radioisotopes in use today have half-value periods of a few days. Of those which have a sufficiently long half-life, only those which can be calibrated in absolute disintegration rates are acceptable for preparation of standards. These isotopes, which emit both beta and gamma rays and which are known to have a mode of disintegration suitable for applying the coincidence method of calibration, may be standardized by this method. The number of isotopes that satisfy both these requirements is very limited at present.

Isotopes that have short half-periods and that have a known disintegration scheme may be measured with a beta-ray standard of some other isotope with fair accuracy if (1) it is known that a beta ray or positron is emitted for every disintegration, and (2) the maximum energy of the beta-ray spectrum of the standard is not too different from that of the beta-ray spectrum of the isotope to be measured. This procedure is more accurate for comparing beta rays with maximum energies above about 0.5 Mev, where back-scattering effects will be largely compensated if the same backing material is used for the sample and the standard.

Comparisons of Samples of Isotopes Differing From the Standard

In comparing samples of isotopes differing from the standards, all precautions outlined for the comparisons of the same isotope must be employed and the thickness of the counter window in milligrams per square centimeter must be known. In addition, an absorption curve for the beta rays from the standard and a similar absorption curve for the beta rays from the sample must be taken. This procedure consists in observing the counting rates for each when different known thicknesses of aluminum in milligrams per square centimeter are interposed between the source and the counter. The data are plotted on coordinate paper having a logarithmic scale on the y-axis and a linear scale on the x-axis, plotting counts per second on the y-axis and thickness on the x-axis. These graphs will be very nearly straight lines. An example is given here taken from the instructions accompanying the RaD+E beta-ray standards issued by the National Bureau of Standards. Table 1 shows the data, in which the first column is the thickness of the aluminum absorbers in milligrams per square centimeter, the second column is the observed counting rate, and the third column is the net counting rate, that is, the observed counting rate minus the background rate in counts per second.

TABLE 1. *Data for absorption curve shown in figure 1*

Air absorber: Sample 2 cm from window is 2 cm$\times\frac{1.18 \text{ mg}}{\text{cm}^3}$=2.4 mg/cm².
Window absorber, 3.0 mg/cm²; background counting rate, 0.5 c/s.

Aluminum mg/cm²	Observed counting rate c/s	Net counting rate c/s
7.6	23.5	23.0
13.9	21.5	21.0
20.0	20.0	19.5
34.5	16.5	16.0
65	11.0	10.5
91	7.2	6.7
120	5.0	4.5
168	2.5	2.0
220	1.3	0.8

In figure 1 these data are plotted as outlined, the line through the observed points is extrapolated to zero thickness to give a zero absorber counting rate of 27.5 c/s. Assuming this represents the data for the standard, the procedure is repeated for the unknown sample. If the zero-thickness extrapolated counting rate thus obtained is, say, 35.2 c/s, the disintegration rate, R, of the sample is

$$R=\frac{35.2}{27.5}\times(\text{disintegration rate of the standard}).$$

Preparation of Working Standards

Since calibrated standards supplied by the National Bureau of Standards can be expected to maintain their calibration only when handled carefully by trained personnel, it is desirable that laboratories prepare their own working standards. This applies particularly to beta-ray standards deposited on metal planchets, such as the RaD+E standards.

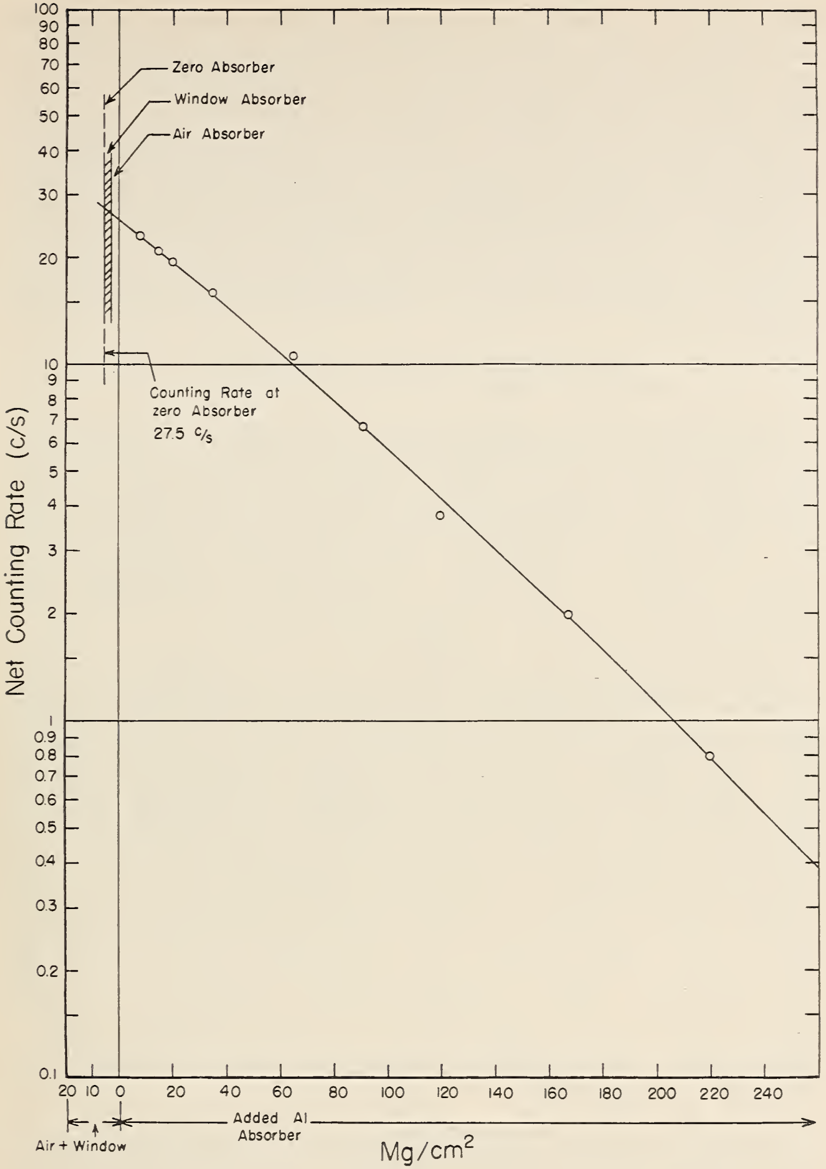

FIGURE 1. *Curve showing method of extrapolation to zero thickness of absorber.*

There is another advantage in the preparation of working standards in the laboratory. This arises from the fact that this permits the primary standards in many instances to be prepared as gamma-ray standards consisting of a solution sealed in a glass ampoule, from which it never need be removed for use. An example is furnished by the Co^{60}

standards now available from the National Bureau of Standards. They consist of 5 ml of solution containing a total of 1.5 rutherfords (rd) (1.5×10^6 disintegrations per second) in one series, and 0.15 rd in another. They may be used to calibrate unknown solutions of Co^{60} by comparing the gamma-ray activity of the unknown solution in a similar ampoule, using a gamma-ray electroscope for the purpose. The ratio of these readings, corrected for background, provides the information for computing the strength of the unknown solution in terms of a disintegration rate. If we represent the electroscope readings of the standard by S and that of the unknown by U, the disintegration rate for the unknown is given by

$$\frac{U}{S} \times \text{(disintegration rate of standard).}$$

As an illustrative problem, assume that a gamma-ray standard of the isotope under measurement is available, having a value of 7.82rd. The electroscope to be used has a background of 0.015 div/sec. With the standard at a selected position, the reading obtained is 3.165 div/sec. Net reading=3.150 div/sec. With the unknown in the same position, the reading is 1.180 div/sec. Net reading=1.165 div/sec. The value of the unknown then is $\frac{1.165}{3.150} \times 7.82 = 2.892$ rd.

This previously unknown sample has now been calibrated. It can be made up to a standard volume, diluted in known ratios, and aliquots taken to produce deposits of appropriate activity for beta-ray standards. For example, if Co^{60} beta-ray working standards are to be prepared, using the National Bureau of Standards 5-ml gamma-ray standards, the unknown solution will have a volume of 5 ml at the time of the gamma-ray comparison. Let us assume that the value found for this sample is 2.892 rd from the preceding example and a working standard of 289.2 μrd (289.2 dis/sec) is desired. The 5-ml-solution is made up to 500 ml in a volumetric flask, and 50 microliters pipetted from this 500-ml solution. This 50 μl contains 289.2 μrd and may be evaporated conveniently on a metal disk to produce a working standard.

Quantitative Comparison of Isotopes for Which Disintegration Schemes are Unknown

We have seen that without a knowledge of the disintegration scheme it is impossible to make reliable measurements of radioisotopes in terms of disintegration rates. The disintegration scheme serves to determine whether the mode of disintegration is such that disintegration rates can be obtained from observations which can be made conveniently. For example, if the isotope happens to be a positron emitter but also disintegrates in part by electron capture, there is no convenient way of measuring the disintegration rate since it is difficult to determine the number of disintegrations proceeding by electron capture which only can be detected by virtue of the resulting characteristic x-radiation.

In the case of those isotopes for which disintegration schemes are lacking or for which it is known that the mode of disintegration does not lend itself to measurement of disintegration rates, an alternative method of comparison of activities of sources is available if the isotope emits gamma rays. This alternative does not give disintegration rates, but it can, when properly applied, yield reliable comparisons of sources in various laboratories. For a particular isotope that emits gamma rays it is obvious that the intensity of the gamma radiation emitted is proportional to the amount of the isotope present. However, it is a well-known fact that electroscopes and ionization chambers used for measuring gamma rays have sensitivities which vary greatly from each other because of variations in size, materials, geometrical disposition of the source, etc. Therefore, the comparison of source strengths by the gamma-ray method is a valid method only when confined to the same isotope and when using the same electroscope in the same geometrical relation to the source. This is the basic pronciple of all measurements of radium by the gamma-ray method.

A method has been suggested for extension of the gamma-ray method of comparison of sources to all laboratories. To obtain uniform results with such a method, no matter where the comparisons are made, we require (1) a standard instrument and (2) standard geometry. The requirement for the standard instrument is that it shall yield the same response for two equal samples of any isotope, regardless of the energies of the gamma rays emitted by these isotopes. There is a unit of gamma radiation that is defined without reference to the energy of the gamma ray—the roentgen. It is defined as that quantity of roentgen or gamma radiation such that the associated corpuscular emission (secondary beta radiation) per 0.001293 g of air, produces, in air, ions carrying 1 electrostatic unit of electricity of either sign. Therefore, an ionization instrument properly designed to measure roentgens will satisfy the requirement of a standard instrument. To measure the the strength of a radioactive source we must be able to measure the roentgens per unit time at a standard distance.

The Roentgen Per Hour at a Meter

These consideration lead to the suggestion [1] that the unit of time be 1 hr and the distance 1 m. This leads to convenient magnitudes for sources in common use and also provides an arrangement where the distance of the source from the meter is such that small accidental variations in distance will not produce serious errors, which otherwise would occur, since the response of the instrument varies inversely as the square of the distance from the source. Having arrived at this ex-

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[1] E. U. Condon and L. F. Curtiss, Phys. Rev. **69**, 672 (1946).

perimental arrangement, we find that we are actually using a unit for comparison of gamma-ray sources which is defined as 1 roentgen per hour at a distance of 1 m, or a roentgen per hour at a meter, which can be abbreviated rhm.

Units

This leads us to a consideration of units for expression of disintegration rates. When the unit of time is clearly specified, there is no urgent need for a name to designate a disintegration rate. However, the same could be said about most physical quantities that have names assigned to them. The name serves to select a particular quantity as a unit and automatically defines the fundamental units employed.

The Curie

In 1910 at the Radiology Congress in Brussels the name curie was applied to the amount of radon in equilibrium with 1 g of pure radium. In 1930 the International Radium Standards Commission extended this definition to include the equilibrium quantity of any decay product of radium, with the comment, "The Commission does not favor its extension to members outside the Ra family."[2] However, the use of the curie in referring to disintegration rates indiscriminately has occurred in numerous places in the literature on radioactivity. Unfortunately, it has been used frequently when no disintegration rate could have been measured and even when it was not intended to specify a disintegration rate. As originally defined and as amended in 1930, the curie refers to the rate of disintegration of 1 g of radium, since 1 curie of radon, by virtue of its definition as the quantity in equilibrium with 1 g of radium, is also that amount of radon (or any other member of the radium family), which has a rate of disintegration equal to 1 g of radium.

Consequently, the curie can only be applied when it is intended to refer to rate of disintegration. Any other use has no meaning and has lead to widespread confusion. Although the rate of disintegration of 1 g of radium has never been measured with great accuracy, and the exact value is in dispute to the order of 3 or 4 percent, the National Bureau of Standards has adopted the arbitrary value of 3.700×10^{10} disintegrations per second for the curie when applied to isotopes other than members of the radium family. At some later date when the value of the curie is more accurately known, it may be desirable to modify this figure.

The Rutherford

For many purposes a unit for the disintegration rate can be used that is smaller than the curie and which can be specified exactly and independently of any natural constants, such as the rate of decay of radium. A convenient quantity for a unit is that quantity of radioisotope that

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[2] Rev. Modern Phys. **3**, 432 (1931).

disintegrates at the rate of a million disintegrations per second. The name rutherford (abbreviated rd) has been suggested for this unit (see footnote 1). There are a number of features that should make this unit easy to use. The numerical magnitude is easy to remember:

$$\begin{aligned} 1\ \text{rutherford (rd)} &= 10^6\ \text{disintegrations per sec,} \\ 1\ \text{millirutherford (mrd)} &= 10^3\ \text{disintegrations per sec,} \\ 1\ \text{microrutherford } (\mu\text{rd}) &= 1\ \text{disintegration per sec.} \end{aligned}$$

It is also a quantity of a size frequently used in the laboratory. For example, a therapeutic dose of many isotopes will be of the order of 100 rd, beta-ray sources for use with mica-window bell-type counters will be of the order of 100 to 500 μrd, and the weakest source that can be measured with any accuracy with these counters is of the order of 1 μrd. Tracer samples will usually be of the order of 1 rd.

The use of the rutherford in data presupposes that a disintegration rate has been measured and that this rate is expressed in terms of disintegrations per second. This procedure, if rigidly followed, removes all confusion regarding units and renders data reported from different laboratories directly comparable on an absolute basis. While the size of the unit is convenient, no special merit can be claimed for this feature, since in a subject where numerical values range over values differing by many powers of 10, as is true in nuclear physics, exponents indicating various powers of 10 must be used, no matter what size of unit is selected.

Corrections for Decay of Sources

In measurements of radioisotopes one is always confronted with the necessity of knowing the strength of a source at some particular time, which may not be, and usually is not, the time at which it was last measured. This requires a knowledge of the half-value period, T, or the decay constant, λ, where

$$\lambda = \frac{0.693}{T}.$$

These corrections for decay involve considerable time to compute if made by direct substitution in the usual expression $N = N_0 e^{-\lambda t}$, where N is the amount at the desired time t, and N_0 the amount measured at some time taken as $t=0$, particularly if only the value of T is known, as is usually the case. This work can be simplified considerably by use of the graph in figure 2. On the y-axis the numbers from 1 to 2 are plotted on a logarithmic scale. On the x-axis the values of fractional half-periods are plotted. Knowing the time since the last measurement, t, and the half-period, T, the value of the fraction t/T is computed. Place a straightedge parallel to the y-axis at the point on the x-axis corresponding to this value, and read the decay factor, f, corresponding to the intersection of the straight with the diagonal. The value N at time t is then N_0/f, if N_0 is the value at the last measurement and t is the time since that measurement.

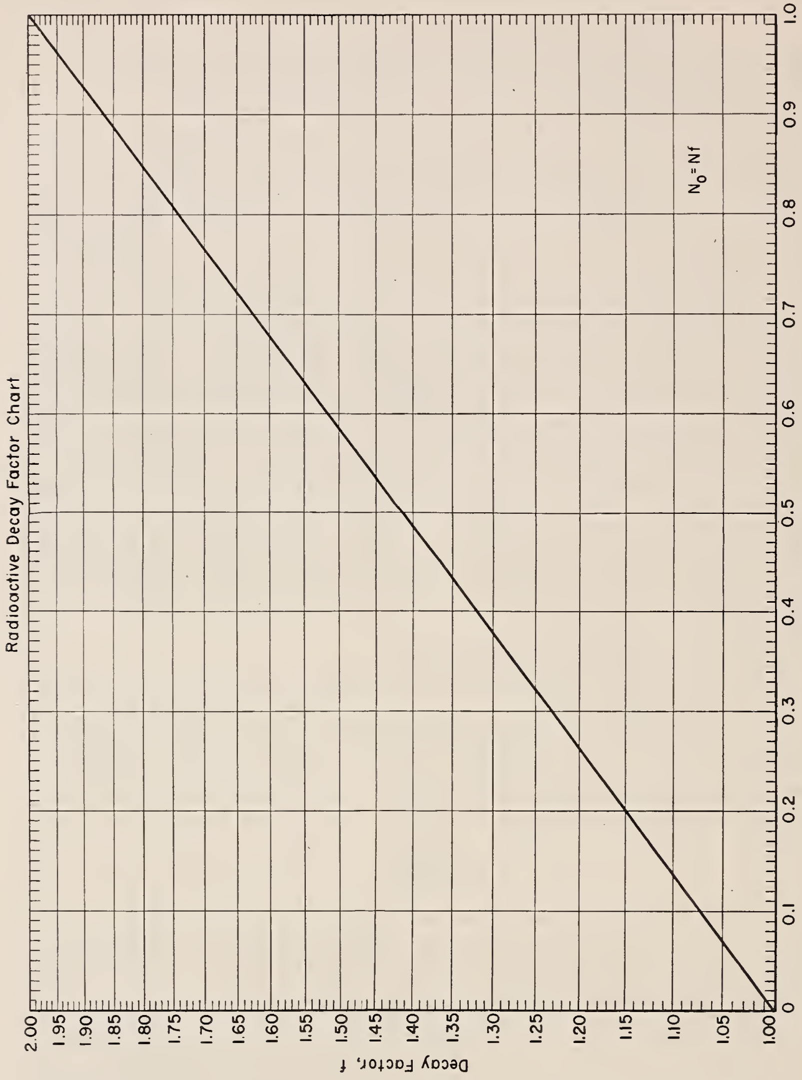

FIGURE 2. *Graph for determination of decay of radioisotopes.*

There are two specific ways in which the graph can be used. If N_0 represents the amount present at the time of measurement, for which it is assumed $t=0$, the decay factor for some subsequent time t can be used to compute the amount N present at time t by the relation

$$N=N_0/f$$

If the activity is measured at some time t subsequent to the time for which t is assigned the value of zero and the amount at this arbitrary zero time is required, it can be computed from the relation

$$N_0 = Nf,$$

where N represents the amount at the time of measurement.

The detailed use of the chart will now be illustrated by numerical examples. First let us assume that a sample of I^{131} is measured and found to be 10.5 rd and 2.5 days have elapsed since the measurement. To determine the present activity, we use the relation $N = N_0/f$, where N_0 represents the original measurement. To determine f we note that the half-period for I^{131} is 8 days. Therefore,

$$t/T = \frac{2.5}{8} = 0.31.$$

From the graph the value of f for this fractional half-period is 1.24. Therefore,

$$N = \frac{10.5}{1.24} = 8.47 \text{ rd}.$$

Now let us assume that the problem is the same, except that 14 days have elapsed since the original measurement. Now

$$t/T = \frac{14}{8} = 1.75 = 1 + 0.75.$$

For $t/T = 1$ we have the partial decay factor of 2.
For $t/T = 0.75$ the partial decay factor from the graph is 1.68. Therefore,

$$f = 2 \times 1.68 = 3.36.$$

Then

$$N = \frac{10.5}{3.36} = 3.12.$$

Now let us assume that a sample of Co^{60}, for which $T = 5.3$ years, is measured and found to contain 38.5 rd. It is required to find the activity 3.5 years prior to the measurement. The fractional half-period is

$$\frac{3.5}{5.3} = 0.66.$$

From the graph we determine f for this fractional half-period as 1.58. We now compute N_0 from the equation

$$N_0 = Nf = 38.5 \times 1.58 = 60.8 \text{ rd}.$$

Let us now assume that we require the activity of this sample of Co^{60} at a time 19.8 years prior to the measurement. The fractional half-period now is

$$\frac{19.8}{5.3}=3.74=1+1+1+0.74.$$

For each full half-period we have a partial decay factor of 2. For the 0.74 fraction we determine from the graph a partial decay factor of 1.67. Therefore,

$$f=2\times2\times2\times1.67=13.36$$

and

$$N_0=38.5\times13.36=514\text{ rd.}$$

WASHINGTON, January 20, 1948.

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