Electron Ejection from an Atomically Clean Tungsten Surface by Helium and Neon Metastable Atoms*

D. A. MacLennan†
Physics Department, University of California, Berkeley, California
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The absolute electron yield γ^m of helium and neon metastable atoms incident on an atomically clean polycrystalline tungsten surface has been determined. The value of γ^m for helium excited by 28-volt electrons is 0.306 ± 0.025, where $^1S_0$ and $^3S_1$ yields are equal within an experimental error of 20%; the value of γ^m for neon is 0.215 ± 0.020. The contribution of each of the two neon metastable states to γ^m has not been resolved in this determination. These results are consistent with present theory, which predicts that the absolute electron yield of slow rare-gas metastable atoms and ions incident on an atomically clean tungsten surface should be the same. Nitrogen and air contamination of the tungsten surface has been observed to reduce the electron yield of helium metastable atoms. This reduction is approximately 45% for nitrogen and 80% for air. Penning cross sections for the ionization of argon by helium and neon metastable atoms have been obtained from the yield data to an estimated accuracy of $\pm30\%$. They are: 9×10^{-16} cm^2 for both $^1S_0$ and $^3S_0$ helium metastable atoms, and 11×10^{-16} cm^2 for an unresolved mixture of $^3P_0$ and $^3P_2$ neon metastable atoms.

I. INTRODUCTION

ELECTRON ejection from metal surfaces by incident positive ions and metastable atoms by virtue of their potential energy has long been the subject of experimental and theoretical investigation.

Within the last fifteen years Hagstrum did some excellent experimental work in studying the yield and ejected electron energy distribution of rare-gas positive ions incident on atomically clean metal surfaces. Of special interest here is his work with low-energy noble-gas ions incident on an atomically clean polycrystalline tungsten surface.[1,2]

Electron ejection from a metal surface by metastable atoms was first established by Webb[3] for mercury metastable atoms incident on a nickel surface. Further work using mercury metastable atoms was done by Couliette[4] and Sonkin.[5] Oliphant[6] first observed electron ejection from a metal surface (flashed but gas-covered molybdenum) by helium metastable atoms. Oliphant produced his metastable atoms by glancing ions off the walls of a gas-covered metal surface. These metastable atoms could have appreciable kinetic energy. Green,[7] using techniques similar to those of Oliphant, extended the work to include neon and argon metastable atoms. In 1938, Dorrestein and Smit,[8] using the absolute helium metastable excitation cross sections obtained by Maier-Leibnitz,[9] estimated the helium metastable electron yields from cleaned but probably gas-covered platinum to be 0.24 and 0.48 for triplet and singlet states, respectively. Stebbings[10] measured the helium metastable electron yield from chemically cleaned but unflashed gold. He concluded that the electron yield for triplets was being observed; his value for this yield is 0.29. Hasted[11] extended this work to include the helium metastable atom yield on tungsten, molybdenum, and tantalum surfaces flashed to 1700°C. The vacuum conditions used were such that the measurements were made on a gas-covered surface, possibly nitrogen and oxygen being introduced into the system via a small leak. Hasted's measured values of the electron yield are 0.14 for tungsten, 0.11 for molybdenum, and 0.25 for platinum on flashed surfaces. These yields are in each case higher for contaminated surfaces in contradiction to the present work.

Early theoretical treatments of electron ejection by positive ions or metastable atoms, by virtue of their potential energy, considered several processes: the tunneling of an electron to populate the excited level of the atom; an Auger transition in which an excited atom is de-excited, giving up the excitation energy to a metal electron; and an Auger transition in which an ion is neutralized by an electron in the metal, falling to the ground state of the atom and giving its energy to another metal electron. Hagstrum[1,12,13] found a number of experimental results which existing theory did not explain. In a semiquantitative theory Hagstrum[14] attempted to explain the experimental results. One of his conclusions is that on an atomically clean tungsten surface, slow (small kinetic energy) rare-gas metastable atoms and ions should exhibit the same electron yield. The reason for this is that metastable atoms are ionized by the tunneling of the excited electron to the metal; both incident ions and metastable atoms are ions when they eject electrons.

The present measurement of the absolute electron

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† Present address: General Electric Company, Research and Development Center, Schenectady, New York.
[1] H. D. Hagstrum, Phys. Rev. **96**, 325 (1954).
[2] H. D. Hagstrum, Phys. Rev. **104**, 317 (1956).
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[9] H. Maier-Leibnitz, Z. Physik **95**, 499 (1935).
[10] R. F. Stebbings, Proc. Roy. Soc. (London) **A241**, 270 (1957).
[11] J. B. Hasted, J. Appl. Phys. **30**, 23 (1959).
[12] H. D. Hagstrum, Phys. Rev. **89**, 244 (1953).
[13] H. D. Hagstrum, Phys. Rev. **91**, 543 (1953).
[14] H. D. Hagstrum, Phys. Rev. **96**, 336 (1954).

yield serves as a check on Hagstrum's theory on potential ejection. The investigation of the effect of nitrogen and air contamination of the tungsten surface on the yield serves to resolve the discrepancy between the Hasted measurement and the present measurement. As a by-product of the yield measurement, Penning cross sections for the ionization of argon by helium and neon metastable atoms are estimated.

II. EXPERIMENTAL

A. Method and Procedure

The method used in the determination of the absolute electron yield γ^m is that of Stebbings.[10] A metastable beam, here helium or neon, is directed through a collision chamber enclosing a reaction volume onto the surface to be investigated, here atomically clean polycrystalline tungsten. Figure 1 shows a schematic of the collision chamber used in the present measurement. The method involves the introduction of argon into the collision chamber. Argon ion current produced by Penning ionization of argon by helium or neon metastable atoms is measured as a function of argon pressure. Each ion measured represents the loss of one metastable atom. Since the metastable atoms can be elastically scattered by argon, the electron yield γ^m of the nonmagnetic stainless steel (ss) electrodes, Fig. 1, must be first obtained in terms of the tungsten target yield γ^m. This is done by scattering the metastable atomic beam in its parent gas from the tungsten target to the ss electrodes. By measuring the ejected electron current from both the tungsten target (ϑ_W) and the ss electrodes (ϑ_{ss}) as a function of the parent gas pressure P, the ratio of the yields can be obtained:

$$\xi=\frac{\gamma^m}{\gamma_{(SS)}{}^m}=-\frac{\partial\vartheta_W}{\partial P}\Big/\frac{\partial\vartheta_{ss}}{\partial P}. \tag{1}$$

By introducing argon into the collision chamber and measuring the Penning ionized argon current I_i and the metastable atom ejected electron current from both the tungsten target I_W and the stainless steel electrodes I_{ss} as a function of argon pressure P_{Ar}, the electron yield γ^m of the tungsten target can in principle be obtained. A 5-mil tungsten wire inside the collision chamber, Fig. 1, collects the argon ion current. In principle

$$\gamma^m=-\frac{\partial(I_W+\xi I_{ss})}{\partial P_{Ar}}\Big/\frac{\partial I_i}{\partial P_{Ar}}. \tag{2}$$

The experimental tube, having a Pyrex glass envelope, quartz insulating spacers, and nonmagnetic stainless steel and tungsten electrodes, is divided into two main sections: a source for producing metastable atoms by electron impact and a collision chamber in which γ^m and the metastable atomic beam intensity is measured. The source is enclosed in a separate Pyrex glass envelope and is fed helium or neon at a pressure of almost 0.1 Torr. In the design of the experimental tube, it was decided to continuously pump the collision chamber, ensuring clean surfaces, and for simplicity of construction to make no provision for pumping the source other than by the metastable exit hole (8-mil diam).

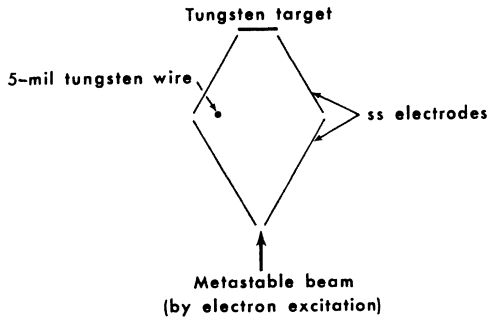

FIG. 1. Collision chamber schematic. Shown is the cross-sectional view. The ss (nonmagnetic stainless steel) electrodes are cylindrically symmetric with respect to the metastable beam axis.

The collision chamber electrodes, Fig. 1, consist of two cone-shaped nonmagnetic stainless steel electrodes, a tungsten target, and a 5-mil tungsten wire. Both tungsten electrodes can be cleaned by direct current heating. Penning ions are collected by the 5-mil wire; scattered metastable atoms are collected and contained by the ss electrodes. Rare gases from the source are pumped from the collision chamber at a steady background pressure of less than 1×10^{-5} Torr. During the various measurements the collision chamber rare-gas pressure ranges up to 1×10^{-3} Torr.

A 200-G magnetic field is used to collimate metastable source electrons, greatly increasing the metastable beam intensity.

Because of the tube construction, the collision chamber rare-gas pressure appears as a partial pressure at steady state in the source envelope; at the relative magnitude of the pressures used, any change in the metastable beam current, including a possible admixture of argon metastable atoms, is small and is linear with the collision chamber pressure. Scattering of the metastable beam outside of the source envelope, but prior to entering the collision chamber, is also linear with the collision chamber pressure in the pressure range of interest because of the small path length involved. In the same pressure range, changes in ϑ_W and I_i of Eqs. (1) and (2) are not linear with collision chamber pressure because of the much longer metastable atom path lengths. Corrections can thus be made for the above linear changes using constants α and β. Equation (1) becomes

$$\xi=\frac{\gamma^m}{\gamma_{(SS)}{}^m}=-\left(\frac{\partial\vartheta_W}{\partial P}+\alpha\right)\Big/\frac{\partial\vartheta_{ss}}{\partial P}. \tag{3}$$

Equation (2) becomes

$$\gamma^m = -\left(\frac{\partial(I_W + \xi I_{ss})}{\partial P_{Ar}} + \beta\right) \Big/ \frac{\partial I_i}{\partial P_{Ar}}. \quad (4)$$

Account must be taken of the argon ion secondary electron current. Hagstrum's[1] value for the argon ion yield is used for the tungsten electrodes. The yield of argon ions on the ss electrodes was obtained by allowing ions at energies between 30 and 100 eV to enter the collision chamber and measuring the ss ion and ejected electron currents.

Prior to taking measurements on γ^m, the experimental system was checked to ensure satisfactory operation. The collision chamber electrodes were checked for their effectiveness in the collection of Penning ions and ejected electrons. Saturation of collected current with increasing potentials on the collision chamber electrodes indicated satisfactory collection of the ions and ejected electrons.

Curves for metastable excitation by electron impact for helium and neon under a range of source conditions indicate satisfactory operation and supply an energy scale.

Since photo-ionization of argon by helium and neon resonance photons was thought to be an important source of error in the present measurement, data were taken on the relative intensity of the photon and metastable atom secondary electron current at the tungsten target using time of flight pulse resolution techniques. It was found that photons contribute little to the error in the present determination of γ^m.

The value of ξ is not affected by resonance photon scattering for the reason that with the experimental tube configuration and pressures used any resonance photon reaching the collision chamber is self-reversed. This self-reversal is such that the metastable-atom–ground-state-atom cross section is at least two orders of magnitude greater than the effective photon–ground-state-atom cross section.

B. Purity and Cleanliness

The atomically clean state of the polycrystalline tungsten surface is produced and ensured through the use of ultra-high vacuum, degassing of the tube electrodes, flashing the tungsten surface, and cataphoresis of the helium, neon, and argon gases used. Critical to the atomically clean state of the target is the nature of the physical adsorption of the noble gases used.

The ultra-high vacuum system, constructed of Pyrex glass, employs a mercury diffusion pump isolated from the vacuum system by two liquid-nitrogen traps. After a 48-h 400°C bake-out, a vacuum in the experimental tube collision chamber of less than 2×10^{-10} Torr was obtained for extended periods of time.

Prior to assembly of the experimental tube, the stainless steel electrodes were outgassed in a high vacuum at 900°C for 3 h.

The tungsten target was initially cleaned by heating to 1700°C for 1 h, followed by heating to 2200°K for 20 min in ultra-high vacuum. During the course of measurements the target was flashed frequently (5-min intervals) to maintain the clean state. As indicated later in Fig. 4, after an initial cleaning, the yield γ^m remains constant and independent of time of heating and temperature (to the highest used, about 2300°K). For this paper, the surface flashed to obtain constant yield is "atomically clean."

Cataphoresis,[15–17] the segregation of a minority gas to the cathode of a glow discharge of a predominant gas, is a standard procedure for cleaning the lighter noble gases and was used in the present work to purify helium, neon, and argon. Loeb *et al.*,[18] for example, used this technique for the purification of argon. The noble gases used are supplied in 1-liter flasks and are initially spectroscopically pure.

The surface adsorption of the experimental gases at the operating pressures must be considered. Fortunately helium, neon, and argon are physically adsorbed so weakly that the atomically clean state of the tungsten surface is not significantly altered at the pressures used. Hagstrum[14] discusses the energy of interaction of a noble gas atom with a clean tungsten surface. From these interaction energies, assuming thermal equilibrium, surface adsorption can be roughly estimated.

III. RESULTS

The electron yields of helium and neon metastable atoms incident on an atomically clean polycrystalline surface are:

Metastable atom	Energy of exciting electrons (eV)	Yield
He	20.5	0.318±0.030
He	28	0.306±0.025
Ne	26	0.215±0.020

Errors given include a rms error calculated from the scatter in the yield determinations, a rms error which is the same for each of the above yields, and an estimated systematic error of 5%. Those errors will be discussed presently. The confidence level of the yield errors given is estimated to be 0.60.

The above helium yields can be resolved into yields of singlet and triplet metastable atoms using the observed ratio of the metastable states excited by 28-volt electrons. At 28 volts this ratio of singlets to triplets is 0.40.[19] In calculating the accuracy of the singlet

[15] R. Reisz and H. Diecke, J. Appl. Phys. **25**, 196 (1954).
[16] L. B. Loeb, J. Appl. Phys. **29**, 1369 (1958).
[17] A. L. Schmeltekopf, Jr., J. Appl. Phys. **35**, 1712 (1964).
[18] L. B. Loeb, R. G. Westburg, and H. C. Huang, Phys. Rev. **123**, 43 (1961).
[19] J. L. G. Dugan, H. L. Richards, and E. E. Muschlitz, Jr., 17th Annual Gaseous Electronics Conference, Atlantic City, New Jersey, 1964 (unpublished).

yield determination, it is assumed that the systematic error associated with the 20.5- and the 28-eV yields is the same. The yields of the two helium metastable states are:

State	Yield
2^3S_1	0.318 ± 0.030
2^1S_0	0.280 ± 0.060

The effect of nitrogen and air contamination on the yield of helium metastable atoms from a tungsten surface can be seen in Figs. 2, 3, and 4. Figure 2 shows the percentage of the atomically clean tungsten surface yield versus time after flash for a clean system and for a nitrogen background. It can be concluded from this figure that the nitrogen sticking probability is on the order of 0.5. Figure 3 illustrates the effect of the flash temperature on the yield in ultra-high vacuum with initial nitrogen contamination of the tungsten surface.

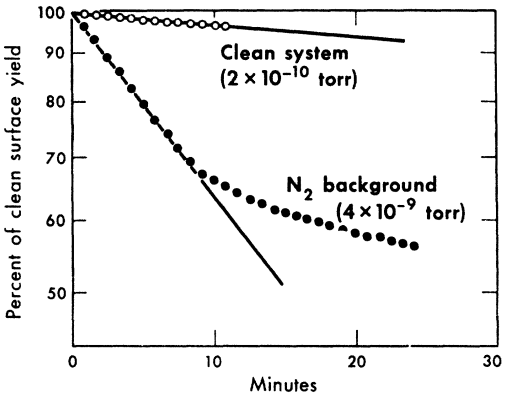

FIG. 2. Percent of the atomically clean tungsten surface electron yield for incident helium metastable atoms versus time after flash in a clean system and in a nitrogen background.

Figure 4 is the same as Fig. 3 except that the initial contamination is air and the flash times are varied.

Penning cross sections for the ionization of argon by metastable atoms have been determined as a by-product of the yield data to an estimated accuracy of $\pm30\%$. They are 9×10^{-16} cm^2 for both $^1S_0$ and $^3S_0$ helium metastable atoms and 11×10^{-16} cm^2 for an unresolved mixture of $^3P_0$ and $^3P_2$ neon metastable atoms.

Error in these cross sections is primarily due to the argon pressure and the metastable path length uncertainties. Yield determinations require only that the ion-gauge ion current be linear with pressure while cross-section measurements require ion-gauge calibration. In the present work the ion gauge used was uncalibrated; however, the sensitivity of a calibrated gauge of the same type was used. The experimental tube, designed with only yield measurements considered, allows a cone-shaped metastable beam to enter the collision chamber. This design and the elastic scattering of the metastable beam render the path length uncertain.

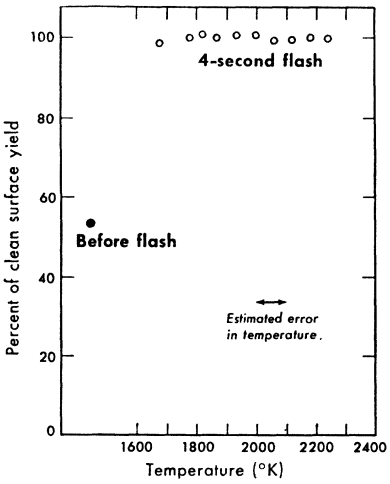

FIG. 3. Percent of the atomically clean tungsten surface electron yield versus flash temperature for a 4-sec flash in a clean system with initial tungsten coating by nitrogen.

In addition to the rms yield error calculated from the scatter in the γ^m determinations, of interest as possible contributions to the yield error are the uncertainties in the measured value of the argon ion electron yield from the ss electrodes, the argon ionization by resonance photons, and the argon ionization by ejected electrons.

The contribution of the ss electron ion yield uncertainty (rms value of 0.004) to the γ^m error is ±0.014 for helium and ±0.12 for neon.

By time-of-flight resolution methods, the neon resonance photon intensity is estimated to be about half of the metastable atomic beam intensity and the helium resonance photon intensity is negligible compared to the helium metastable atomic beam intensity. It is concluded from the relative magnitude of the Penning[20] and photo-ionization[21] cross sections that resonance photons result in a neon γ^m error of less than 1.5% and a yet smaller helium γ^m error.

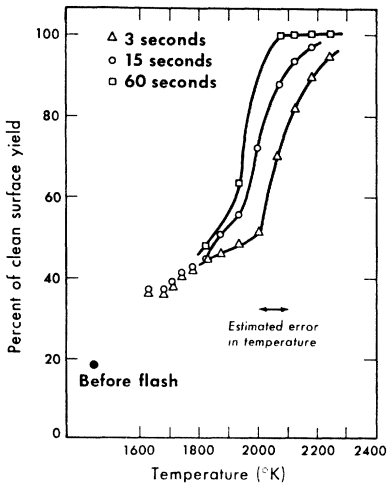

FIG. 4. Percent of the atomically clean tungsten surface electron yield versus flash temperature for 3-, 15-, and 60-sec flash times in a clean system with initial tungsten coating by air.

[20] Table I.

[21] E. W. McDaniel, *Collision Phenomena in Ionized Gases* (John Wiley & Sons, Inc., New York, 1964), p. 344.

The ionization of argon by electrons ejected from the ss electrodes and electrons created by the Penning ionization of argon tend to decrease the determined value of γ^m. These extra argon ions are counted not as ions but as metastable ejected electrons. During measurements of the ion current to the tungsten wire, metastable atom-ejected electrons are retarded back to the ss electrodes. During measurements of the ejected electron current from the ss electrodes, the argon can be ionized by electron impact. Estimated from the ratio of the averaged electron ionization cross section[22] to the Penning cross section, this effective increase in the measured ejected electron current (corresponding to a decrease in γ^m) is approximately 1.5% of the Penning ion production at low argon pressure and is approximately linear with argon pressure in the region of interest. A correction for this effective increase in the measured ejected electron current is included in the constant β of Eq. (4).

Systematic errors such as those caused by nonlinearity in ion gauges, electrometers, pen recorders, and measurement procedures are assigned a value of 5%.

IV. DISCUSSION

Electron yields of helium and neon ions incident on an atomically clean polycrystalline tungsten surface were measured down to 10 eV by Hagstrum[1]; these yields extrapolated to zero energy are 0.293 and 0.213, respectively, and are equal within experimental error to the electron yields obtained in the present investigation for helium and neon metastable atoms as predicted by Hagstrum.[14]

Hasted[11] in an air background of 2×10^{-6} Torr obtained the yield of 0.14 electrons per helium metastable atom incident on a flashed (1700°C) tungsten surface by extrapolating the yield from 15 sec after flash to zero time on a semilogarithmic plot. His yield was not observable prior to 15 sec after flash. He argued that the rate of change of the clean surface area with time is equal to the extent of the gas-free surface area multiplied by a constant proportional to the background pressure and the sticking probability. He concluded from this that for less than a monolayer of background gas on the surface, the semilogarithmic plot of the yield versus time after flash should be a straight line with a slope depending upon the sticking probability and the pressure. Having observed a straight-line semilogarithmic decrease in yield with a slope indicating a sticking probability of considerably less than unity, Hasted reasonably concluded that monolayer formation was being observed and that the atomically clean surface yield could be obtained by extrapolating to zero time after flash. Hasted's results are in disagreement with those of the present work: a yield of 0.31 for helium metastable atoms on atomically clean tungsten and a nitrogen gas sticking probability of roughly 0.5 on atomically clean tungsten.

[22] W. Bleakney, Phys. Rev. **36**, 1303 (1930).

TABLE I. Penning cross sections for the ionization of argon by helium and neon metastable atoms obtained in the present work compared with other reported values.

Incident metastable	Cross section Å²	Measured by
He $^3S_1$	9[a]	Present work
	7.6	Muschlitz and Scholette[b]
	6.6	Benton et al.[c]
	3.8	Phelps[d]
He $^1S_0$	9	Present work
	7.6	Muschlitz and Scholette[b]
	12	Phelps[d]
Ne (mixture of $^3P_0$ and $^3P_2$)	11	Present work
	2.6	Biondi[e]
	6.7	Schut and Smit[f]

[a] Estimated 30% experimental error.
[b] E. E. Muschlitz, Jr., and W. P. Scholette, J. Chem. Phys. **36**, 3368 (1962).
[c] E. E. Benton, E. E. Ferguson, F. A. Matsen, and W. W. Robertson, Phys. Rev. **128**, 206 (1962).
[d] A. V. Phelps, Westinghouse Research Report No. 6-94439-6-P3, 1957 (unpublished).
[e] M. A. Biondi, Phys. Rev. **88**, 660 (1962).
[f] T. G. Schut and J. A. Smit, Physica **10**, 440 (1943).

Because of this disagreement, studies of the yield for helium metastable atoms as a function of time after flash, such as depicted by Fig. 2, were made with increasing nitrogen background pressure as a parameter. With increasing nitrogen background pressure, the initial linear decrease in yield (Fig. 2) occurs with increasing rapidity. The initial decrease is not seen 15 sec after flash at a background pressure of 2×10^{-6} Torr of nitrogen, and at this pressure the semilogarithmic plot of the yield versus time after flash (in the 5-min interval observed by Hasted) is nearly linear having a slope consistent with a sticking probability considerably less than unity. Here the small sticking probability is observed on a nitrogen-covered surface.

Extrapolating the semilogarithmic plot of the yield obtained for helium metastable atoms at a nitrogen background pressure of 2×10^{-6} Torr from 15 sec after flash to zero time results in a 0.19 yield. Although this yield is slightly larger than the 0.14 yield observed by Hasted, his sticking probability of considerably less than unity can be understood as having been observed on a gas-covered surface. Since air contamination of the tungsten surface produces a large decrease in the yield (Fig. 4), Hasted's stated air background pressure of 2×10^{-6} Torr and his yield value of 0.14 are consistent with an air-covered surface.

Figures 3 and 4 show that there is a sizeable change in the yield for incident helium metastable atoms going from a contaminated (no flash) to an atomically clean tungsten surface. Figure 2, exhibiting a linear dependence on a semilogarithmic plot for an initial time interval, indicates that the change in yield is linear with the fraction of the surface covered by a monolayer of

contamination. It can be concluded from these figures that the helium metastable beam might be an excellent probe for measuring the state of surface cleanliness. Figure 4 further illustrates the possibilities of using the time and temperature of flash technique in investigating the energy states of gas adsorption.

Some disagreement exists concerning the magnitude of the various rare-gas Penning cross sections. The dependence of these cross sections on energies of the colliding atoms might explain the disagreement since differing techniques were used in the measurements. In Table I, Penning cross sections for the ionization of argon by helium and neon metastable atoms obtained in the present work are compared with other reported values. The present values for helium, with one exception, compare well with others within experimental error (30%). Agreement in the case of neon is not good. Benton *et al.*, Phelps, and Biondi carried out their measurements in an afterglow following a pulsed discharge; other measurements used beam techniques.

ACKNOWLEDGMENTS

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Critical Magnetic Field and Transition Temperature of Synthetic High-Field Superconductors

J. H. P. WATSON
Corning Glass Works, Corning, New York
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Measurements of the critical field $\hat{H}$ and transition temperature $\hat{T}$ of superconducting indium in porous glass have been made using a low-frequency mutual-inductance technique. The pore sizes of the glasses are well characterized, so that 96% of the pore volume is within ±10% of the mean pore diameter d. Pore diameters from 65 to 250 Å were used. Below t ($\equiv T/\hat{T}$) $=0.5$, $\hat{H}$ can be represented approximately by

$$\hat{H}=(3415\pm40)(1-t^2)/d^{(1.00\pm0.14)},$$

where $\hat{H}$ is in kilo-oersteds and d is in Angstrom units. This is in agreement with the predictions of de Gennes and Maki of H_{c2} for type II superconductors in the dirty limit, assuming that the electronic mean free path is proportional to d. Above $t=0.6$, there are deviations from de Gennes's prediction for the d dependence and the t dependence of $\hat{H}$. For the small pore sizes the temperature dependence of $\hat{H}$ is qualitatively similar to the Abrikosov prediction of H_{c2} for type II superconductors; however, near $t=1$ for the largest pore size the temperature dependence of $\hat{H}$ is similar to that for a type I superconductor. The superconducting transition temperature $\hat{T}$ shows a strong dependence upon d, so that $\hat{T}$(65 Å) is 4.23°K compared with 3.4°K for the bulk indium. The dependence of $\hat{T}$ on d is conveniently represented by

$$\hat{T}-T_{\text{bulk}}=1-0.0028\,d,$$

where d is in Angstrom units. The change in $\hat{T}$ may be due to strain, mean-free-path, or surface effects. The samples are similar to inhomogeneous type II superconductors in their magnetic properties, showing hysteresis and flux jumping.

I. INTRODUCTION

SYNTHETIC high-field, high-current superconductors have been made by impregnating porous glass with metal. Magnetic properties of these composites have been described by Bean, Doyle, and Pincus,[1] Bean,[2] and more recently by Watson.[3] The behavior of the samples was similar to inhomogeneous type II superconductors, since they showed hysteresis in the magnetization, flux jumping, and a current-carrying capacity apparently limited by the Lorentz force condition. It was also found that the critical field $\hat{H}$ and the superconducting transition temperature $\hat{T}$ depended strongly upon the pore size of the glass. ($\hat{H}$ and $\hat{T}$ refer to the normal superconducting transition of the filamentary structure. H_c and T_c refer to the bulk metal.)

In this paper measurements of the critical field $\hat{H}$ and the superconducting transition temperature $\hat{T}$ are presented for samples of porous glass containing indium and covering a wide range of pore sizes.

It was found in these measurements that $\hat{H}$ depended strongly upon d, the pore diameter of the glass. Below $t=0.5$, where $t=T/\hat{T}$, $\hat{H}$ varied as $1/d$. In the same temperature range $\hat{H}$ varied approximately as $(1-t^2)$.

[1] C. P. Bean, M. V. Doyle, and A. G. Pincus, Phys. Rev. Letters **9**, 93 (1962).
[2] C. P. Bean, Rev. Mod. Phys. **36**, 31 (1964).
[3] J. H. P. Watson, J. Appl. Phys. **37**, 516 (1966).