

APPARATUS AND DEMONSTRATION NOTES

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This department welcomes brief communications reporting new demonstrations, laboratory equipment, techniques, or materials of interest to teachers of physics. Notes on new applications of older apparatus, measurements supplementing data supplied by manufacturers, information which, while not new, is not generally known, procurement information, and news about apparatus under development may be suitable for publication in this section. Neither the *American Journal of Physics* nor the Editors assume responsibility for the correctness of the information presented. Submit materials to James L. Hunt, *Editor*.

A new tube for Richardson–Dushman experiments

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The Richardson–Dushman equation describes the thermionic emission of electrons from a heated metallic filament. Using data for the current of the emitted electrons as a function of the temperature of the filament, the equation can be used to obtain the work function of the metal. The problem is to find a satisfactory commercial tube to use in the experiment. Pearlstein *et al.*¹ have reported on the use of a commercial phototube; the disadvantage here is that the filament material is unknown. This note reports on the use of the Neva two-electrode electron tube with a tungsten filament; this tube is imported into this country by Klinger.²

The Richardson–Dushman equation predicts that the current density of the emitted electrons at a given temperature T is

$$J = AT^2 \exp(-\varphi/kT), \quad (1)$$

where k is Boltzmann's constant, φ is the work function of the surface, and A is a constant. Taking the natural log of the equation gives

$$\ln(I/T^2) = \text{const} - \varphi/kT. \quad (2)$$

Plotting the variable on the left-hand side as a function of $1/T$ gives a straight line with slope $-\varphi/k$; from this the value of the work function is obtained.

The Klinger tube's filament is a helix made of tungsten wire which is stated to be 0.2 mm in diameter. The anode is an open-ended cylinder which nearly encloses the filament. The maximum heating current for the filament has a maximum value of 5 A, and the current used is normally smaller than this. The assumption is made that the electrons are immediately attracted to the anode and do not form a nearby space-charge region. Operation in this saturation mode requires a potential difference of upwards of 200 V for this tube.

The chief difficulty with experiments involving the Richardson–Dushman equation is finding the temperature of the filament. The information sheets applied with the tube do not give a calibration curve of temperature as a function of heating current. However, the *Taylor Manual*³ has a table of temperature as a function of $I/d^{2/3}$ for tungsten wire, where I is the heating current and d is the diameter of

the filament. The current can be measured to three significant figures, but the diameter is given by the supplier only to one significant figure. Gregory Derry of Loyola College (Baltimore) has measured the diameter of the filament from a tube which was no longer in use, and obtained 0.196 ± 0.008 mm, which is consistent with the 0.20 ± 0.01 -mm value assumed in the calculations below.

Figure 1 is a plot of $\ln(I/T^2)$ as a function of $1/T$; the data were collected by a student group in my sophomore-level modern physics course. The value of the work function calculated from the slope of the graph is 5.2 ± 0.3 eV. There is a 4% uncertainty in the (least-squares) calculation of the slope; the slope may also be systematically high or low by as much as 4% due to the error in the temperature caused by the uncertainty in the diameter of the filament. A second group got a value of 5.3 ± 0.2 eV, and a third value (obtained independently some months later) was 5.2 ± 0.2 eV. The value quoted by Kittel⁴ for the work function of tungsten from thermionic emission data is 4.5 eV. Surface contamination can be expected to make the practical value of the work function higher than that measured under ideal conditions.

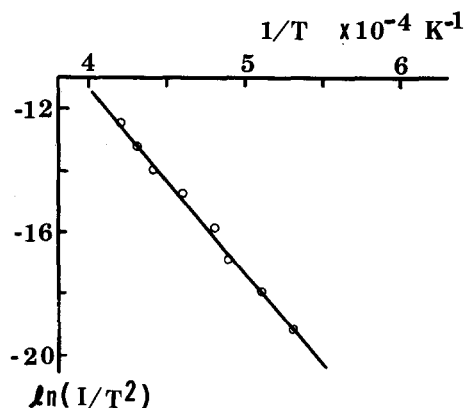


Fig. 1. The slope of this graph is φ/k ; for these data, the value of φ is 5.2 ± 0.3 eV. The current, I , is in mA.

¹Edgar Pearlstein, Gregory Swift, and Kenneth Wright, "Thermionic emission experiment using a phototube," *Am. J. Phys.* **44**, 1184–1186 (1976).

²Model No. KE6770, sold by Klinger Educational Products Corp., 112-19 14th Road, College Point, NY 11356. The cost is \$205.

³*The Lloyd William Taylor Manual of Advanced Undergraduate Experi-*

ments in Physics, edited by Thomas B. Brown (Addison-Wesley, Reading, MA, 1959), pp. 349–350, 442–46. Use of Table 8-3 allows the temperature of the filament to be found from the heating current.

⁴Charles Kittel, *Introduction to Solid State Physics* (Wiley, New York, 1956), 2nd ed., p. 267.

GALILEO: THE WONDER AND DELIGHT OF UNDERSTANDING

The force of rigorous demonstrations such as occur only in mathematics fills me with wonder and delight. From accounts given by gunners, I was already aware of the fact that in the use of cannon and mortars, the maximum range, that is, the one in which the shot goes farthest, is obtained when the elevation is 45° ; but to understand *why* this happens far outweighs the mere information obtained by the testimony of others or even by repeated experiment... . The knowledge of a single fact acquired through a discovery of its causes prepares the mind to understand and ascertain other facts without need of recourse to experiment, precisely as in the present case, where by argumentation alone the Author [Galileo] proves with certainty that the maximum range occurs when the elevation is 45° . He thus demonstrates what has perhaps never been observed in experience, namely, that of other shots those which exceed or fall short of 45° by equal amounts have equal ranges... . Now let us hear the demonstration of this.

Galileo Galilei, *Dialogues Concerning Two New Sciences*, 1638, translated by Henry Crew and Alfonso de Salvio (Macmillan, New York, 1914; reprinted by Dover, New York), p. 276.