

LETTERS

Photoelectric effect

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Photoelectric effect

A N James's article 'Photoelectric effect, a common fundamental error' (*Physics Education* 1973 **8** 382) was recently drawn to our attention. James is critical of the oversimplified description which textbooks usually give of measurements of the stopping potential in photoelectric experiments. If light falls on a photocathode A and the photoelectrons are collected at surface B there is a contact potential difference ($\Phi_B - \Phi_A$) between the two surfaces. The commonly quoted equation erroneously omits this contact potential difference:

$$h\nu - e\Phi_A = eV_s. \quad (1)$$

Up to this point we are in agreement with James. We cannot accept that the idealization in his deduction of equation (2) is reasonable except in very carefully controlled experiments:

$$h\nu - e\Phi_B = eV_s. \quad (2)$$

We must also take issue with his final paragraph, in which he states that if a workfunction is to be measured in this experiment, it is the collector surface which must be clean and uniform since it is the workfunction of this surface which appears in equation (2).

To claim that surface B is the only surface with which care must be taken is to forget the manner in which equation (2) was derived. The Einstein equation gives the maximum kinetic energy of the emitted electrons:

$$E_{\max} = h\nu - e\Phi_A. \quad (3)$$

This kinetic energy is expressed in terms of an applied stopping potential V_s added to the contact potential difference ($\Phi_B - \Phi_A$) between collector B and photocathode A. V_s is just sufficient to reduce the photocurrent to zero.

$$E_{\max} = eV_s + e(\Phi_B - \Phi_A). \quad (4)$$

By subtraction equation (2) is obtained.

There are several difficulties with this derivation, one of which is that it applies only at a temperature of absolute zero. Techniques for temperature correction are available (Condon and Odishaw 1967).

A difficulty which is more directly relevant to James's discussion concerns the contact potential difference ($\Phi_B - \Phi_A$). This potential difference arises because of the physical contact of B and A at some junction in the circuit and not by the juxtaposition of B and A in the phototube. There may, of course, be several intermediate junctions. The troublesome assumption in the derivation of equation (2) is that Φ_B and Φ_A are the same for the exposed surfaces in the phototube as for the surfaces at the junction. This assumption should not be made lightly, particularly in the case of the experimental arrangement likely to be used in a teaching laboratory.

Because there will be several junctions in any circuit for measuring the stopping potential it would appear that equation (2) is itself a simplification. To apply equation (2) to a practical circuit, one must assume that all the contact potential differences in the circuit exactly balance out except for that between B and A (which are in contact at only one point). Thus, in a real experiment, it would seem that there is considerable doubt as to what meaning should be ascribed to the 'workfunction' term in equation (2).

The term 'stopping potential', as usually used, is a misnomer. The photocurrent is reduced to zero by the action of a decelerating field in the phototube. As we have already noted, this field arises from two distinct sources, the externally applied voltage and the intrinsic contact potential difference. What is measurable in this experiment is the externally applied voltage and it is this which is usually termed 'stopping potential'. Failure to recognize this (and, worse, equating the measured V_s to E_{\max}/e) is at the root of the oversimplification which James so rightly deplors.

It may help to consider a hypothetical experiment in which a single metal is used for the entire circuit. The stopping potential might be electromagnetically induced as might the current detection. The value of eV_s is now the maximum kinetic energy of the emitted electrons.

We support James's contention that the most useful classroom experiment on the photoelectric effect is the demonstration of the existence of a cut-off frequency. This is related only to the emitting

surface, and, therefore, does give a reasonable measure of the work function of that surface. If Planck's constant is assumed, then Φ_A may be calculated from the cutoff frequency ν_c .

$$h\nu_c = e\Phi_A,$$

where Φ_A is in volts.

The value obtained for ν_c will depend somewhat on the sensitivity of the current meter used and the intensity of the illumination. In phototubes such as the 92AV the photoelectric yield of the composite photosensitive surface decreases sharply enough in the 'cutoff' region for the 'cutoff' frequency to be determined to within 10% (Jenkins and Trodden 1965).

While the measurement of the 'stopping potential' does not provide a means of determining the workfunction of the emitting surface, the measurement of V_s as a function of ν does provide one of the more important measurements of Planck's constant (or h/e , to be precise), as James points out. Clearly, whatever workfunction appears in equation (2), it does not affect the slope (h/e) of the graph of V_s against ν .

We thank Dr James for raising this matter, as a discussion of the photoelectric effect is a key part of the introduction to modern physics for most students.

E R Hodgson and R K Lambert

Massey University, New Zealand

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Dr James replies

Lambert and Hodgson rightly point out that the photoelectric effect depends on temperature. The two main features are the thermal fluctuations in energy (about 25 meV at room temperature) and the variation of the workfunction of a conductor with temperature. At temperatures above absolute zero the workfunction is usually defined as the chemical potential of the electrons. The temperature variation is due to changes in the chemical potential of the electrons (the Fermi energy) caused by changes in both the distribution function and the density of states function (these factors influence the change of conductivity with temperature). Such changes lead to the usual thermoelectric effects which if integrated around the circuit would lead to the temperature changes of the contact potential field in the gap of a photoelectric cell. Such temperature changes do not affect the basic argument since the workfunction is defined even though it depends on material and temperature.

With respect to the cleanliness of the photoemitting surface the equation

$$h\nu - e\Phi_B = eV_s$$

is derived solely by conservation of energy and by the existence of an electron chemical potential. If the electrons are in equilibrium with one another throughout the photoemitting surface (ie reasonably good conductivity over the whole volume of the emitting layer) then the Fermi level of the emitter is independent of the actual surface structure. Indeed a technique has been described (Berglund C N and Spicer W E 1964 *Physical Review* 136A 1044) in which foreign material is deliberately deposited on the photoemitter (for other reasons) without affecting the Fermi level. A varying workfunction across a patchy surface will lead to electric fields parallel to the surface. Provided the anode is clean the equipotentials will however be uniform at the anode surface and a sharp stopping potential is defined.

Bacon-Descartes-Mpemba

Robert Galliar's recent (1974) observation of the views of Francis Bacon on the freezing times of water of different temperature is followed by the claim that the Mpemba effect 'was a fairly common piece of physics about this time'.

He may well be right, yet I must risk being a bore by quoting a letter of mine in *New Scientist* (1971) which indicates a very different interpretation of Bacon's attitude to the question. The extract is from Thorndike (1923): 'Credulity, in contrast to the sceptical attitude of modern science, is a characteristic of Bacon's experimental method. He declares, it is true, that experiment disproves many false notions such as that hot water freezes faster than cold . . . but we have already heard such beliefs questioned by Albertus Magnus and others'.

Eric Deeson

Newman College, Birmingham

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Another interesting historical reference to this effect is to be found in a letter dated 11 February 1775. Joseph Black, Professor of Chemistry at Edinburgh at that time, records his observations on 'The supposed effect of boiling upon water, in disposing it to freeze more readily'. (Black J 1775 *Phil. Trans. R. Soc.* 65 124). His investigations concern the formation of ice in two samples of water having the same initial temperature but differing in that one