Response of a Thermocouple Junction to Shock Waves in Copper

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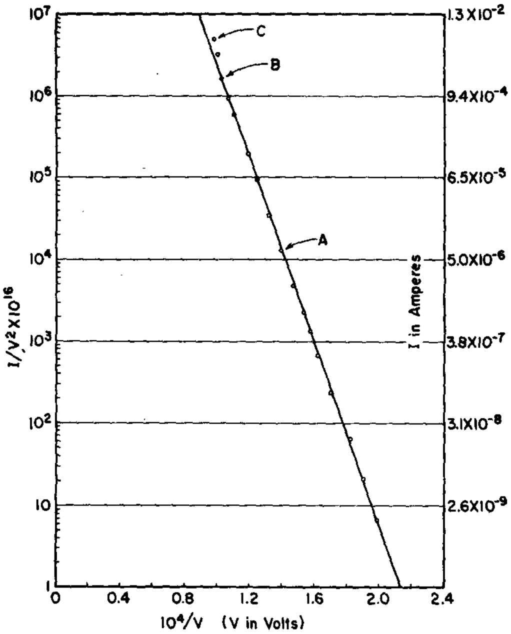

FIG. 1. Fowler–Nordheim plot of current–voltage data from clean tungsten electrodes. (A) represents point where the transition radiation was first detected on the anode. At (B) the radiation has increased in intensity, while the anode has reached a temperature of ~700°C. At (C) the radiation is still visible against an incandescent background (1050°C).

become visible as a result of local bombardment heating of the anode by highly collimated beams of field-emitted electrons originating at small protrusions or bumps on the cathode. However, our results on refractory metal anodes suggest that visible transition radiation will generally precede incandescent radiation resulting from bombardment heating, since the onset of the two types of radiation occur at quite different current levels [for example, compare points (A) and (B) of Fig. 1].

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[1] D. J. DeGeeter, J. Appl. Phys. **34**, 919 (1963).
[2] E. M. Lyman, F. Konrad, and T. Casale, "Coordinated Science Laboratory Progress Report," University of Illinois (December 1962–February 1963), p. 48.
[3] J. E. Lilienfeld, Physik. Z. **20**, 280 (1919).
[4] I. Frank and V. Ginsburg, J. Phys. USSR **9**, 353 (1945).
[5] G. Beck, Phys. Rev. **74**, 795 (1948).
[6] H. Boersch, C. Radeloff, and G. Sauerbrey, Z. Physik **165**, 464 (1961).
[7] R. P. Little and W. T. Whitney, J. Appl. Phys. **34**, 3141 (1963).

Response of a Thermocouple Junction to Shock Waves in Copper*

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IN the course of experiments to measure temperatures in the vicinity of craters produced by high-velocity impact, thermocouples were attached to the surfaces of metal targets and embedded in them. In many cases, a small jump in output voltage was observed to occur at the time of impact. This was followed by a slower rise in temperature as heat was conducted from the crater to the region of the thermocouple. It was suspected that the initial temperature jump was caused by the irreversible heating produced by passage of a strong wave.

These thermocouple voltage measurements were made with a microvolt meter having a response time of about ½ sec, so no detailed observations of the initial voltage rise could be made. The small voltages obtained (20 μV) precluded the use of a fast-response amplifier and oscilloscope to observe the thermocouple output.

To produce waves strong enough to be easily measured, a thin copper target was used with a constantan wire silver-soldered to the rear surface to form a thermocouple. A 4.76-mm-diam copper ball impacted at velocities ranging from 0.5 to 2.1 km/sec. With this system, thermocouple voltages up to 60 mV were observed using a Tektronix type 533 oscilloscope with a type E preamplifier. Noise in the system required the use of the differential amplifier, although its frequency response was inadequate for the fast transient present. These preliminary experiments clearly demonstrated the feasibility of using a thermocouple junction to measure wave strength. However, a definite relationship between voltage output and wave parameters could not be determined because of the difficulty of hitting directly over the thermocouple, thus making it impossible to calculate the actual wave strength at the junction.

To produce plane waves, the system shown in Fig. 1 was devised. A Tektronix type B preamplifier was used with a type 533 oscilloscope. The transient response of this sytem was adequate to observe details in the voltage rise and decay in the junction. A typical voltage waveform is also shown in Fig. 1. The voltage rises rapidly (within 2 μsec), levels off, and then may swing widely in either polarity. The waveform after the initial rise and leveling varies from shot to shot and depends on the mode of disintegration of target and junction. Various interesting oscillations related to wave transit times in wire and target are observed in the voltage output, but only the magnitude of the first step is considered in the data reported here. We interpret the initial voltage step as being due to the establishment and decay of a brief "stationary" flow condition between the rear face of the target and the thermocouple wire.

The results of a series of shots on 1.68-mm-thick copper plates, 24 AWG constantan wires, and copper and 24 T4 aluminum projectiles are shown in Fig. 2. A straight line is drawn through the copper data for reference. The indicated error comes from uncertainty in reading the oscilloscope trace due to noise with the signal or to the occurrence of more than one step in the voltage trace during the first 4 μsec. The theoretical curve for the alumi-

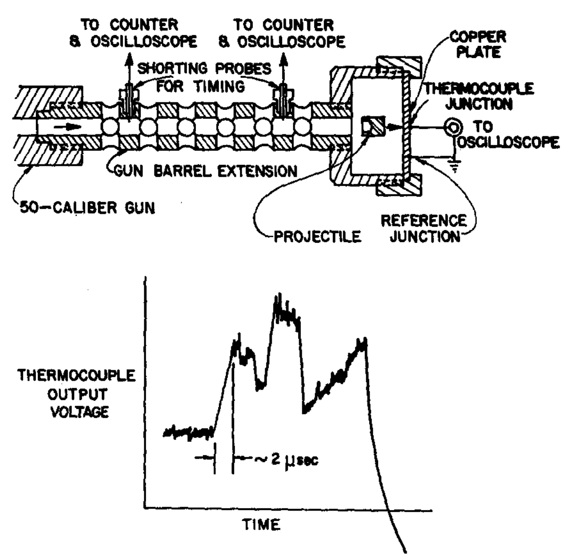

FIG. 1. Gun, projectile, and thin-plate target used to measure response of a thermocouple junction to a shock wave. A typical waveform of thermocouple output voltage is also shown.

num impact data is generated as follows. Equation-of-state data[1,2] and plane shock-wave theory are used to compute the expected particle velocities in copper produced by known-velocity impacts by aluminum projectiles. The curve through the copper data is then used to give the expected output voltages for these particle velocities.

At the maximum velocities used here, shock-wave pressure is only about 0.3 Mbar which gives a shock-wave temperature rise in copper of about 180°C and should give a thermocouple output of less than 10 mV. The observed output of 57 mV suggests a nonequilibrium condition at the wavefront which is not adequately described by shock theory alone. Also, shock heating of the junction (and subsequent cooling as rarefaction waves move in) occurs too rapidly to explain the slow voltage buildup observed. Heat generation by friction as the thermocouple wire flows is a possible explanation for the high temperature indicated.

Figure 3 shows the observed thermocouple output plotted vs shock pressure. The straight line of Fig. 2 is shown as a dashed line. For comparison, the temperature rise behind the wave, temperature rise after expansion back to zero pressure, internal energy behind the wave, and the product of pressure and specific volume are shown. None of these quantities appear to be directly proportional to the observed output voltage.

The use of a thermocouple junction for measuring wave strength has wide possibilities for application in any solid, liquid, or gas system where strong waves are present. A calibrated junction can be coupled to the system and the unknown wave strength determined from measured voltages and known shock-impedance properties of the materials involved. We have made tests using a copper plate, with constantan junction, cemented to a titanium plate. The results are similar to those shown in Fig. 2. For attachment to a plate, the reference junction of Fig. 1 is bent away from the plate so that it does not receive a wave until after the wave in the measuring junction is recorded. A similar arrangement would have to be used in a liquid. In some cases, the region surrounding the thermocouple junction would have to be evacuated to avoid the presence of strong waves along the thermocouple wire.

These initial results do not give conclusive evidence as to what is being measured, and at this time, any system used as a transducer requires calibration with known waves. No special effort was made to produce highly uniform junctions for these tests. Variable amounts of silver solder were used with crude hand-torch soldering methods. The results indicate the desirability of further research into the phenomena involved and further development of materials and geometries for particular applications.

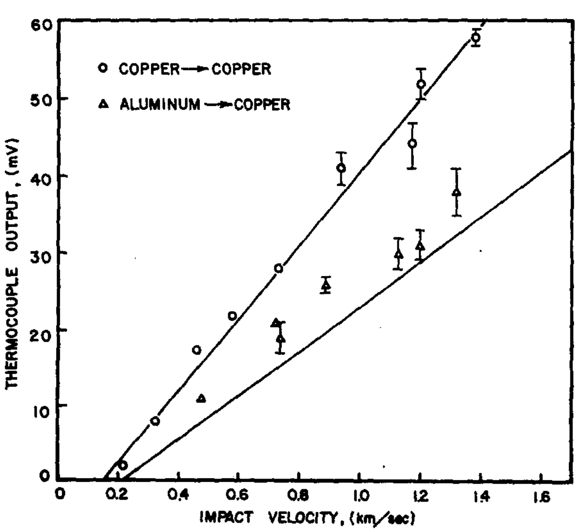

FIG. 2. Thermocouple voltage vs impact velocity for the impact of copper and aluminum projectiles on copper.

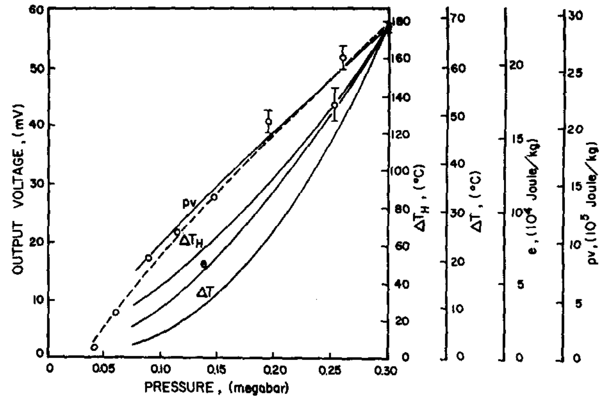

FIG. 3. Comparisons of temperature rise behind a shock wave ΔT_H; temperature rise after adiabatic expansion to zero pressure ΔT; internal energy behind a shock e; the product of pressure and specific volume pv; and thermocouple output voltage. All quantities are plotted vs shock-wave pressure. The dashed line is the straight line through the copper data of Fig. 2.

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1 R. G. McQueen and S. P. Marsh, J. Appl. Phys. 31, 1253 (1960).
2 John M. Walsh and Russell H. Christian, Phys. Rev. 97, 1544 (1955).

Mechanisms of Electrical Conduction in Thin Insulating Films

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IN a recent article, Harris[1] concluded on the basis of "current curve shapes" that conduction in his thin films of BeO was due mainly to Schottky emission rather than to tunneling. It is the purpose of this communication to show that Harris's curve shape analysis cannot be used to distinguish between Schottky emission and tunneling. Further, an analysis of his data which include the temperature characteristics points to tunneling as the actual mechanism of conduction.

The Schottky equation[2] in simplified form is

$$I=\alpha \exp(\beta V^{\frac{1}{2}}),$$

where α is the thermionic current obtained at zero field as given by the Richardson–Dushman equation,[3] and β is a constant involving temperature, insulator dielectric constant, and insulator thickness. Harris shows that a Fowler–Nordheim graph ($\log I/V^2$ vs $1/V$) of this equation results in a curve with a definite minimum. He states that tunneling currents are described by the Fowler–Nordheim equation,[4]

$$I=AV^2 \exp(-B/V),$$

and therefore a Fowler–Nordheim graph for the tunneling current will give a straight line of negative slope. Since his experimental curves resembled those obtained from the Schottky equation, he concluded that he was observing Schottky emission.

The above analysis neglects the fact that the Fowler–Nordheim equation is applicable only at high voltages. At low voltages, the tunneling current, like all other currents, must obey the Ohmic relation $I=\gamma V$. That the tunneling current does this is well documented.[5–12] A Fowler–Nordheim graph of the Ohmic region