

mixture of these states. If two fluorine atoms interact so as to form and evaporate as F_2 , the ϵ represents half of the energy to cause this. If the evaporation occurs as fluorine atoms, then it is just the energy of evaporation of a single fluorine atom from the clean molybdenum surface.

- ¹ R. L. Aamodt, L. J. Brown, and B. D. Nichols, *J. Appl. Phys.* **33**, 2080 (1962).
² G. E. Moore and H. W. Allison, *J. Chem. Phys.* **23**, 1609 (1955).
³ S. Gladstone, K. J. Laidler, and H. Eyring, *The Theory of Rate Processes* (McGraw-Hill Book Company, Inc., New York, 1941), p. 365.
⁴ J. E. Jahnke and F. Emde, *Tables of Functions with Formulae and Curves* (Dover Publications, Inc., New York, 1941).
⁵ M. Metlay and G. E. Kimball, *J. Chem. Phys.* **16**, 779 (1948).
⁶ J. Becker, *Advances in Catalysis* (Academic Press Inc., New York, 1955), Vol. 7, p. 159.
⁷ I. Langmuir and J. B. Taylor, *Phys. Rev.* **44**, 423 (1933).
⁸ P. Kisliuk, *Phys. Rev.* **122**, 405 (1961).
⁹ L. R. Blue, "Dekin—A Desorption Kinetics Code-A1" (1963).

Work Function in the System Thorium-Rhenium

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THE purpose of this communication is to compare some experimental results reported recently by Anderson *et al.* with similar theoretical predictions presented by Gyftopoulos and Levine.

Anderson *et al.*¹ give experimental results on the work function of and the desorption rate from a rhenium surface partially or fully covered by thorium. One of their conclusions is that their experimental measurements are in disagreement with the theoretical results published by Gyftopoulos and Levine.² Unfortunately, Anderson *et al.* have been misled to this conclusion by misquoting Ref. 2 and by failing to verify it through use of the formalism therein.

To see this clearly, consider the theoretical formula for the variation of the work function of any metallic surface covered by any monatomic metallic vapor:²

$$\frac{\phi_m - \phi_c(\theta)}{\phi_m - \phi_f} = 1 - G(\theta) \left[1 - \frac{0.76 \times 10^{-18} \sigma_f \theta \cos \beta}{(1 + \alpha/4\pi\epsilon_0 R^2)(1 + 9\alpha\sigma_f^{3/2} \theta^{3/2}/4\pi\epsilon_0)} \right], \quad (1)$$

where all the terms have been defined in Ref. 2.

For the adsorption system Th-Re, tabulated physical constants necessary for the calculation are:

covalent radius of Re:	$r_m = 1.28 \times 10^{-10} \text{ m}$
covalent radius of Th:	$r_f = 1.65 \times 10^{-10} \text{ m}$
sum of covalent radii:	$R = 2.93 \times 10^{-10} \text{ m}$
polarizability of Th ² :	$\alpha = 8.2 \times 10^{-30} \text{ F-m}^2$

For the particular reproducible specimens, of Re immersed in Th, investigated by Anderson *et al.*, the following constants were reported¹:

work function of bare surface:	$\phi_m = 4.85 \text{ eV}$
work function at one monolayer:	$\phi_f = 3.33 \text{ eV}$
adsorbate density at one monolayer:	$\sigma_f = 7.95 \times 10^{18} / \text{m}^2$
adsorbate density at maximum	$\sigma = \sigma_f \theta_m = 4.2 \times 10^{18} / \text{m}^2$
electron emission:	
work function at maximum	$\phi_c = 3.15 \text{ eV}$
electron emission ³ :	
substrate crystallographic structure:	(0001)

On the basis of these physical constants and experimental data, Eq. (1) can be numerically evaluated. Indeed:

$$\begin{aligned} \sigma_m &= 2\sigma_f = 15.9 \times 10^{18} / \text{m}^2,^4 \\ \cos \beta &= 0.86,^5 \\ \frac{\phi_m - \phi_c(\theta)}{\phi_m - \phi_f} &= 1 - G(\theta) \left[1 - \frac{5.1 \times 10^{-19} \sigma_f \theta}{1 + 6.6 \times 10^{-29} \sigma_f^{3/2} \theta^{3/2}} \right]. \quad (2) \end{aligned}$$

The plot of Eq. (2) is in excellent agreement with the work function measurements of Ref. (1) for all values of θ . In particular, at

the point of maximum emission where $\theta_m = 4.2/7.95 = 0.53$, $\sigma_f \theta_m = 4.2 \times 10^{18}$, $G(\theta_m) = 0.46$, Eq. (2) yields:

$$\phi_c = 3.1 \text{ eV.}$$

This is to be compared with the experimental value 3.15 eV.¹

In conclusion, the theory advanced in Ref. 2 is in agreement with the results of Anderson *et al.*, at least as far as the numbers quoted in Ref. 1 are concerned.

Regarding thermal desorption, a completely theoretical derivation of desorption energies of composite surfaces for both atoms and ions, without adjustable parameters, is given in an article by Levine and Gyftopoulos that is to be published.⁶

¹ J. Anderson, W. E. Danforth, and A. J. Williams, III, *J. Appl. Phys.* **34**, 2260 (1963).

² E. P. Gyftopoulos and J. D. Levine, *J. Appl. Phys.* **33**, 67 (1962).

³ This value is calculated with a Richardson constant $A = 75$. The formalism of Ref. 2 requires $A = 120$ but this does not introduce any appreciable difference.

⁴ See Ref. 2, p. 71. Anderson *et al.* guess this density to be equal to $15.3 \times 10^{18} \text{ m}^{-2}$.

⁵ See Ref. 2, Eq. (12), p. 70.

⁶ J. D. Levine and E. P. Gyftopoulos, *J. Surface Sci.* (to be published).

High-Frequency Oscillations in a Thermal Plasma

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LOW-FREQUENCY ion oscillations are frequently observed in thermal plasma devices, such as power converter plasma diodes,¹ and are associated with drift of the plasma electrons. Birdsall and Bridges² have suggested that an instability of the drifting electrons should give rise to high-frequency oscillations with period near the electron transit time across the device, and that such oscillations decrease the average electron current and density. Relaxation of the resultant charge imbalance would produce a cycle of the ion oscillation.

Oscillations of this type have been observed in a thermal cesium plasma. The apparatus is a cesium-vapor diode utilizing a 1.27-cm-($\frac{1}{2}$ -in.) diam electron-bombardment-heated tungsten button, opposed by a moveable cold plate, operating in an axial magnetic field.

With the diode short circuited and the button temperature such that an excess of ions is available, smooth ion oscillations are observed as diode current fluctuations with frequency depending only on the button-to-plate spacing. In addition, an L-C circuit and detector picks up a signal with frequency 500 to 1000 times

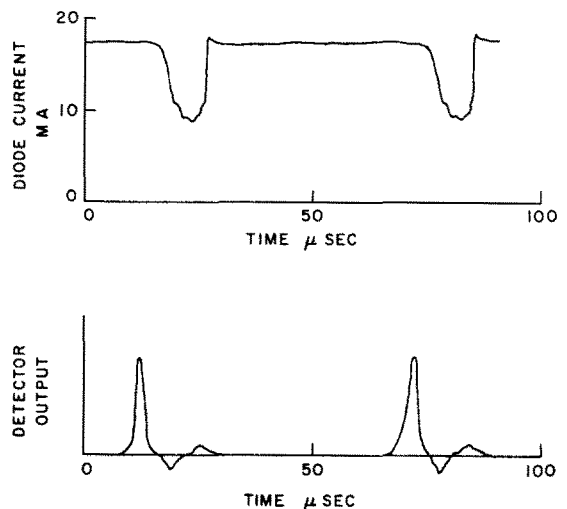


FIG. 1. Waveform of low-frequency fluctuations and the envelope of high-frequency bursts.

TABLE I. Oscillation frequency and burst frequency as a function of diode spacing.

Diode spacing	Oscillation frequency	Burst frequency
0.56 cm	100 kc/sec	86 Mc/sec
0.73	76	65
0.89	61	50
0.96	52	48
1.25	45	43
1.35	39	35
1.54	37	34
1.89	30	31

higher occurring in bursts once each cycle of the lower frequency fluctuation. Figure 1, prepared from oscilloscope photographs, shows the waveform of the low-frequency fluctuations and the envelope of the high-frequency bursts. (The small pips of alternating sign occurring in the detector output are the low-frequency current fluctuations, differentiated by the coupling coil).

Table I lists the observed low and high frequencies as a function of diode spacing.

The high-frequency bursts always occur in conjunction with the low-frequency fluctuations. The detailed shape of the high-frequency envelope may vary somewhat as conditions are changed, but the burst always occurs slightly before or at the onset of each low-frequency current pulse. The higher frequency is 500 to 1000 times the lower, this ratio being near the square root of the ion-electron mass ratio.

¹ K. P. Luke and F. E. Jamerson, *J. Appl. Phys.* **32**, 321 (1962).
² C. K. Birdsall and W. B. Bridges, *J. Appl. Phys.* **32**, 2611 (1961).

Erratum: A Complete E, P, V, T, S Thermodynamic Description of Metals Based on the P, u Mirror-Image Approximation

[*J. Appl. Phys.* **34**, 746 (1963)]

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IN a recent paper we concluded that the mirror image (about P_H, u_H) of the Hugoniot must approach the isentropic expansion curve that passes through the shocked state P_H, u_H as $P_H \rightarrow 0$. While this conclusion is valid, the proof given in the second half of the Appendix for the general fluid is incorrect for it is based on the erroneous statement that "any isentrope in the P, u plane can be generated from any other isentrope by a translation in the u -direction." (This statement is true only for the trivial case where the initial thermodynamic states of the isentropes are identical.)

The previous proof may be redone in the following way. Consider the Hugoniot and isentrope passing through the initial state $P_0, V_0, S_0, u_0 = 0$, and the expansion isentrope from the shocked state $P_H, V_H, S_H, u_H > 0$, with $dP/du > 0$ on all three curves. Then,

$$u(P_H, S_0) = \int_{P_0}^{P_H} (dP/\rho c)_{S_0},$$

$$u(P_0, S_H) = u_H - \int_{P_0}^{P_H} (dP/\rho c)_{S_H};$$

and $Q = [u_H - u(P_H, S_0)]/u(P_0, S_H) > 1$ for a thermodynamic fluid with $[\partial(\rho c)/\partial S]_P < 0$, i.e., with $\partial^2 V/\partial P \partial S < 0$. Thus, for such a fluid (e.g., a γ -law gas), $Q \neq 1$, which implies that the isentropes cannot be generated by a translation in the u direction. But $u(P_H, S_H) - u(P_H, S_0) \alpha (P_H - P_0)^2$ and $u_H \alpha P_H - P_0$ for $P_H \approx P_0$, from which it follows that $u(P_0, S_H)/u_H \rightarrow 0$ as $P_H \rightarrow P_0$, since

$$u(P_0, S_H)/u_H < [u_H - u(P_H, S_0)]/u_H \alpha (P_H - P_0)^2.$$

If we now consider the mirror images of all three curves (the

initial state is now $P_0, V_0, S_0, 2u_H$, and $dP/du < 0$), we find

$$R = [2u_H - u(P_0, S_H)]/u_H \rightarrow 0 \quad \text{as} \quad P_H \rightarrow P_0,$$

here, $u(P_0, S_H)$ is on the mirror-image curve.

Another proof is based on the elegant analysis of Walsh and Christian,¹ who derived the maximum and minimum values for $[u(P_0, S_H) - u_H]/u_H$ under the assumption that $(\partial E/\partial V)_{P=P_0} = \text{constant}$. Both these values [see their Eqs. (15) and (22)] approach 1 as $P_H \rightarrow P_0$, implying that $R \rightarrow 0$, too.

¹ J. W. Walsh and R. H. Christian, *Phys. Rev.* **97**, 1544 (1955).

Erratum: Ultrasonic Amplification and Non-Ohmic Behavior in CdS and ZnO

[*J. Appl. Phys.* **34**, 1548 (1963)]

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THE equation at bottom of p. 1551 should be corrected to read as follows:

$$v_d \geq v_s [1 + 4(\omega_c/\omega_D)]^{1/2}.$$

On the basis of this corrected equation, the last two sentences in the same paragraph should be changed to read:

Sample 2 is the worst case and gives $v_d \geq 1.3 v_s$ as the condition for round-trip gain. Therefore, to the extent that reflection losses at the sample boundaries can be neglected, we expect all of the samples in Table I to show non-Ohmic behavior approximately as soon as the carrier drift velocity exceeds the sound velocity.

Erratum: Ultrasonic-Diffraction Shutters for Optical Maser Oscillators

[*J. Appl. Phys.* **34**, 2984 (1963)]

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ALL references made to Fig. 6 in the paragraph beginning at the bottom of the second column of p. 2986 and continuing to the bottom of p. 2987 should, instead, make reference to Fig. 7. The sweep speed for Fig. 4 on p. 2986 should read: 20 μ sec/div rather than 10 μ sec/div.

Erratum: Retarding Field Technique for Measuring Sublimation from Dispenser and Oxide Cathodes

[*J. Appl. Phys.* **34**, 200 (1963)]

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THE ordinate scale (evaporation rate . . . monolayers/sec . . .) of Fig. 12, p. 205, should be multiplied everywhere by a factor of 10.

Announcements

American Institute of Physics Handbook, Second Edition

The second edition of *The American Institute of Physics Handbook*, which is a thorough revision and expansion based on suggestions made by a distinguished panel of physicists, has recently been published by McGraw-Hill Book Company (Price \$29.75).