have lines about 75 oersteds wide,[4] it is apparent that a sizable decrease in K_1 has been obtained. An estimate of K_1 seems impossible because of our inability to take into account the effect of ceramic imperfections (pores, etc.) and of deviations from uniform distribution of cobalt in the specimen. From the papers of Bozorth[2] and Healy[4] we may take $+2\times10^6$ and -5×10^4, respectively, as the anisotropy constants of cobalt and nickel ferrites. These values, obtained for the most nearly stoichiometric crystals, do, of course, lead to a prediction of zero anisotropy for $\alpha=0.025$ if K_1 is considered a purely additive atomic property.

In Fig. 2, we show some typical results of measurements of line width as a function of temperature in the region 20°C to 350°C. The curves with $\alpha\ll\alpha_0$ and $\alpha\lesssim\alpha_0$ quite obviously behave as expected. The latter case is particularly gratifying in that it is in general very difficult to conclude that line width changes in polycrystalline materials are not due simply to such causes as changes in grain size. Since such contributions to line width will always decrease with M_s, an increase in width with temperature seems very strong proof that we are dealing with a case in which anisotropy is largely determining the width. The curves corresponding to $\alpha>\alpha_0$ show the initial precipitous decrease predicted but do not go to very low values. This may be due to nonuniform cobalt distribution. If this is the case, other ceramic procedures may help, and the narrowness of the line at this first minimum for $\alpha>\alpha_0$ can be used as a "quality control" of the process. This work is in progress.

We want to express our appreciation to Dr. S. L. Blum and Mr. J. Zneimer who supervised the preparation of the specimens discussed in this paper.

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[4] D. W. Healy, Jr., Phys. Rev. 86, 1009 (1952).

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Work Function of Lead*

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The work functions of twelve lead surfaces have been determined by measurement of their contact differences of potential with respect to barium reference surfaces of known work function. The lead surfaces were prepared by subjecting Hilger's spectroscopic lead to intensive outgassing followed by fractional distillation, redistillation, and deposition on glass targets. The barium surfaces were prepared by a similar standardized technique which yields surfaces constant and reproducible to 0.01 ev. Measurement was by the electron beam method, and the time lapse between deposition and measurement of a fresh surface was five seconds.

The contact difference of potential for Ba−Pb is found to be 1.48±0.01 v. The work function of lead, referred to a Ba work function of 2.52 ev, is then 4.00±0.02 ev. No drift of work function exceeding 0.01 ev was found on aging. Since the minimal time required for deposition of a monolayer of gas is large with respect to the metal deposition-measurement interval, it is concluded (1) that the film of gaseous contaminants adsorbed by a lead surface during equilibration is insufficiently dense to affect the work function, and (2) that the observed work function is probably characteristic of clean lead.

WE report here further results from a program of work function studies in which the contact difference of potential between the "unknown" metal and a reference metal of known function, barium, is measured in a barium gettered vacuum. Lead was selected for study because existing data for this metal were obtained under experimental conditions which are no longer regarded as adequate. The present measurements furnish evidence, not available heretofore, for the conclusion that lead surfaces which are initially clean undergo no detectable change of work function on prolonged exposure to the residual gas present in a sealed-off, barium-gettered tube.

TUBE DESIGN. OUTGASSING PROCEDURES

The tubes, in which all the steps involved in the preparation and measurement of the lead and barium films were carried out, were similar to those employed for copper[1] except for the design of the lead vaporizers. Since molten lead alloys with metals of the tungsten group on prolonged contact, the first lead vaporizers (Fig. 1) were 45–60° silica cones set in close fitting conical heaters of 25-mil tungsten wire. The use of twin cones provides insurance against the loss of a tube from failure of a single heating element and increases the total lead charge to 4–5 grams. The lead was Hilger's spectroscopic standard material containing 0.0001% bismuth as the only impurity which can be estimated.

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[1] P. A. Anderson, Phys. Rev. 76, 388 (1949).

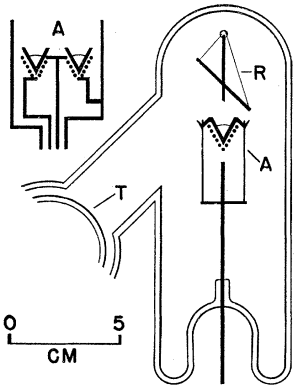

FIG. 1. Lead vaporizers. The "first vaporizers," *A*, are silica cones with hold-down ears and 25-mil tungsten wire heaters. The second vaporizer, *R*, is a 3×4 cm grid of 1-mil tungsten foil. T=glass target of measuring tube. For detail of *R* and tube, see reference 1.

Before the barium and lead charges were introduced, the tube was baked on the pumps at 450° for 24 hours and all of its metal components were subjected to repetitive induction or Joule heating to their tolerable temperature limits. After loading and before sealoff, the following operations were performed in order: (1) The tube was baked at 260°C for 40 hours. (2) The unmelted barium was held for 8 hours at a temperature just below that at which vaporization was detectable; it was then put through three fusion-solidification cycles. (3) The lead charges were melted and solidified nine times. During this treatment the black suboxide initially present as a visible film on the surface of the molten lead was decomposed and the surface remained mirror-like thereafter. (4) The tube was given a final bake of 40 hours at 260°. (5) The lead and barium were put through three more fusion-solidification cycles. The tube was then sealed from the pumps and repetitive fusions of the lead and barium continued until the gun-emission test[2] showed no evolution of gas when the metals were melted. Two fusions were sufficient for this purpose.

MEASURING PROCEDURES

The scheme for depositing a thin film of lead on the target involved slow distillation from the silica ovens to the second vaporizer followed by high-temperature flashing of the second vaporizer and nearly instantaneous deposition on the target. The quantity of lead distilled to the second vaporizer in each film deposition sequence was adjusted by noting the opacity of the film formed on a clean section of the glass target; a "thin film" was one which produced a marked darkening of the glass but not an opaque coating. Before any measurements were taken, the thin-film depositions were repeated until a thick, opaque coating of low electrical resistance had been built up on the target. The first series of measurements, comprising observations on six different lead surfaces, was designed to establish the reproducibility of surfaces which had not come to equilibrium with the residual gas in the tube. As each film was laid down, its potential setting was determined as rapidly as possible. The time lapse between deposition and measurement was approximately five seconds. The readings were found to be reproducible to ±0.01 volt.

Measurements on the next series of six lead surfaces were designed to determine the effects of aging. The initial readings were again taken 5 seconds after deposition but the measurements were then continued at two-minute intervals for 30 minutes. Two of the films were measured 12 hours after deposition. In no case was a drift in work function greater than 0.01 ev observed. The homogeneity of the lead surfaces was determined by tipping the tube in such a manner that the electron beam scanned the surfaces along their diameters. Except for the expected anomalies near the lead-glass boundaries at the edges of the films, no work function differences exceeding 0.01 ev were detected in these tests.

The barium films were deposited over the lead by the standardized fractional-multiple distillation technique employed in all of our work. Eight barium surfaces were measured; all were reproducible and constant to ±0.01 volt.

RESULTS

All measurements on the 12 lead and 8 barium surfaces gave contact differences of potential within the limits 1.47–1.49 volts, with lead electronegative to barium. If the work function of barium, well established by the photoelectric measurements of Jamison and Cashman,[3] is taken as 2.52 ev, our measurements give lead a work function of 4.00±0.01 ev. Since the work function of barium is uncertain to one or two hundredths of an electron volt, 4.00±0.02 ev is to be taken as the work function assigned to lead by our measurements.

It has been shown previously[4] that if the time interval between the deposition and initial measurement of a metal surface is small relative to the minimal time required for deposition of a complete monolayer of gas on the surface, and if no drift of work function is observed as the surface comes to equilibrium with the residual gas of the tube, the following conclusions are possible: (1) The mean sojourn times of the gas molecules which are adsorbed on the metal surface are probably so small that at equilibrium only a small fraction of the surface is covered by gaseous contaminants. (2) If a significant fraction of the equilibrated surface is in fact covered by gas, the work function must be insensitive to the contaminants. (3) If either (1) or (2) is valid, the observed work function can be accepted as characteristic of the clean metal. The present measurements indicate that these conclusions apply to lead. Like zinc, cadmium, and silver, lead is to be classed as a "stable metal" with respect to the work function characteristic. The ductility of lead, furthermore, precludes the existence of the mechanical strains which probably account for some of the work function variations observed in films of the rigid-lattice metals.

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[2] P. A. Anderson, Phys. Rev. **75**, 1207 (1949).

[3] N. C. Jamison and R. J. Cashman, Phys. Rev. **50**, 624 (1936).

[4] P. A. Anderson, Phys. Rev. **57**, 122 (1940).