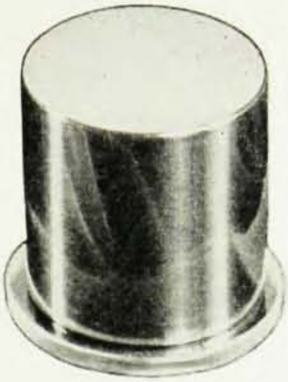
standards of mass



By Lloyd B. Macurdy

The U. S. standard kilogram (shown slightly less than natural size in the photograph above) plays an important role in the work of the National Bureau of Standards, an agency of the government established fifty years ago by act of Congress to insure the uniformity and accuracy of all standards of measurement.

The requirements of modern commerce and industry make uniformity in standards of mass throughout the Nation no less important than uniformity of currency. An even higher degree of uniformity is necessary among reference standards of mass kept by research laboratories to maintain high accuracy in scientific weighing.

High-Precision Measurements

The national standard of mass—a platinum-iridium cylinder about $1\frac{1}{2}$ inches high, $1\frac{1}{2}$ inches in diameter, and having a mass of almost exactly one kilogram—is maintained in a special vault of the National Bureau of Standards. The United States standard kilogram, like the standard meter bar, is a copy of an international standard kept at the International Bureau of Weights and Measures at Sèvres, near Paris. It is known as Prototype Kilogram No. 20. This prototype was established as the national standard by executive order in 1893. Since that time, the pound and other everyday units of mass have been defined by the ratio of their mass to the mass of this kilogram. Occasionally the national standard kilogram is removed from the vault for comparison with the best secondary standards. These secondary standards include other platinum-iridium standards from 1 kilogram to 0.05 mg and two 1-kilogram standards of nickel-chromium alloy. From these standards, values are derived for the working standards in the various customary and metric units used in everyday testing in the Bureau's laboratories.

Weights submitted to the Bureau for calibration include the commercial classes of standards primarily used as the basis of State regulation of weights and measures, the laboratory classes of standards used in scientific research and development, and weights of special design required for industrial or technical work. In some classes of weights, such as those for precise balances, actual values are determined to the required precision; in others, such as weights for testing master track scales, it is only necessary to verify accuracy within specific tolerances. The Bureau's mass laboratory also investigates the degree of constancy and sources of variability in weights and makes studies to designate materials having good corrosion resist-

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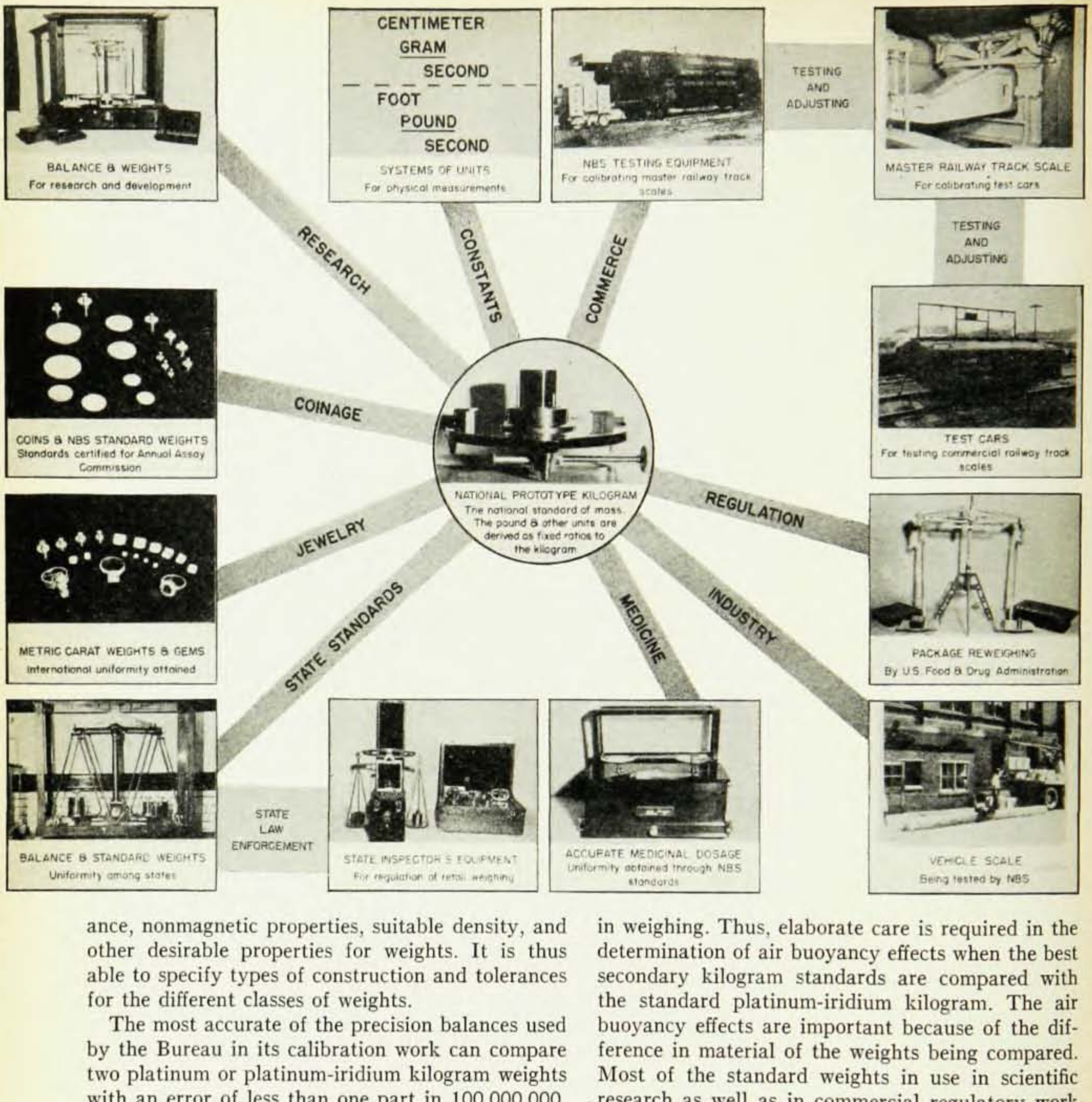


ance, nonmagnetic properties, suitable density, and other desirable properties for weights. It is thus able to specify types of construction and tolerances for the different classes of weights.

The most accurate of the precision balances used by the Bureau in its calibration work can compare two platinum or platinum-iridium kilogram weights with an error of less than one part in 100,000,000. To make possible this high precision, the balance is kept in an air-conditioned room beneath the surface of the ground, and errors due to the heat of the human body are prevented by operating the balance entirely by remote control. Not only is the balance beam arrested and released in this way, but the interchanging of the loads on the pans and the addition of sensitivity weights are also accomplished by remote control.

In determining the exact values of the best secondary standards of mass, the Bureau has found necessary many procedures not ordinarily employed in weighing. Thus, elaborate care is required in the determination of air buoyancy effects when the best secondary kilogram standards are compared with the standard platinum-iridium kilogram. The air buoyancy effects are important because of the difference in material of the weights being compared. Most of the standard weights in use in scientific research as well as in commercial regulatory work are of brass or some alloy of similar density, and the difference in air buoyancy for brass and platinum-iridium kilogram standards amounts to about 75 mg. Two finely finished nickel-chromium kilogram standards with density very near to that of brass ($8.4\ g/cm^3$) are calibrated by comparison with the prototype kilogram in such a way as to include the necessary correction for air buoyancy. In the calibration of these nickel-chromium standards the density of the air is determined with great care. Barometric pressure is accurately measured by means of a sensitive and highly reliable aneroid barometer especially designed for this work. Readings of the barometer between turning points of the balance are used to evaluate momentary fluctuations in air pressure which may have appreciable effects on the turning points. The air temperature in the balance can be accurately measured since lag in thermometers is minimized by the extremely uniform temperatures. Relative humidity inside the balance case is indicated by an electric hygrometer. Once the values of these 1-kg standards are determined, other standards of similar density can be compared with them, without extensive measurements of air density.

In the high-precision calibration of sets of weights, the Bureau follows the general plan established by the International Bureau of Weights and Measures at Sèvres, France. In this method, a summation of the weights from a set is determined by comparison with a known standard, after which the weights are intercompared by a series of weighings consisting of all possible combinations of various loads. These weighings are adjusted by the method of least squares to give values for the larger weights of the set and for a summation of the smaller weights. The weights in this latter summation are then intercompared in similar fashion to obtain values for each of this group of smaller weights and for a still smaller summation. In this way, values are eventually obtained for all the weights in the set, the last series of observations giving values for the smallest weights, which are used in determining the sensitivity of the balance.

In general, the values obtained for the smaller weights will be slightly different from their preliminary values which were used in sensitivity determinations for the various weighings. The new values for the sensitivity weights must therefore be substituted in the computations and the entire computations repeated. Usually after one recomputation the values obtained for the sensitivity weights are identical with those substituted for the sensitivity weights. Because this method accurately subdivides the value of the prototype kilogram to give the values of the sensitivity weights, the results are based entirely on the value of the national standard. This procedure is used in the calibration of the Bureau's best set of platinum-iridium standards from 500 g to 1 mg and for smaller aluminum weights down to 0.05 mg. As standard weights certified by the Bureau are available in various denominations, it is not ordinarily necessary for other laboratories in this country to make these rather tedious computations.

The Bureau maintains accurate secondary standards for the avoirdupois pound, troy pound, and troy ounce, defined by their fixed ratios to the prototype kilogram. Groups of two 1-lb avoirdupois standards, or three 1-lb troy standards, or three 10-ounce troy standards are compared with the best secondary 1 kg standards, the differences in each case being made up with small standard weights from the best platinum-iridium metric set. From these standards of customary units, values are derived for standards used by the States in regulation of commerce and industry.

To provide standards for modern microbalances, the Bureau has recently developed methods for calibrating small standard weights below 100 mg with a precision of one or two ten-millionths of a gram. This precision—10 or 15 times as great as that now obtained by indirect methods of calibration—will permit the weighing of samples about one-tenth as large as formerly. The resultant increase in the field of usefulness of microbalances should mean great savings to workers in such fields as atomic energy, where minute samples must be weighed with high accuracy.

Calibration of these small weights is carried out on high-grade assay balances using the method of double transposition in which loads are interchanged twice and a small sensitivity weight, usually 0.1 mg or 0.05 mg, is added to obtain a sensitivity deflection. Equilibrium points are computed from a series of five or more turning points observed through a reading telescope on a finely divided index scale. The sensitivity is such that 0.1 scale division is equal to about 0.2 microgram. A reading accuracy of about one-twentieth of a scale division or slightly better is readily obtained by experienced observers.

In order to certify values below 100 mg to an accuracy of 0.1 microgram, it is necessary to work down from 1-g standards, intercomparing the weights to be calibrated in all possible combinations, and to repeat the entire computation to obtain values for the sensitivity weights which are accurate subdivisions of the 1-g standards. The reliability of the balances used is such that for weighings expertly carried out under optimum conditions the values obtained by least square adjustment of the weighings are reproducible to 0.1 microgram. Moreover, discrepancies between observed and computed or adjusted values are usually not greater than 0.1 microgram. This accuracy, perhaps the highest ever obtained with the knife-edge type of balance, is of special value in the weighing of radioactive material, making it possible to handle smaller samples with greater safety and to make use of smaller samples at less cost of time and labor.

Refinement of methods permitting high precision in the calibration of extremely small weights has greatly simplified the problem of calibrating quartz microbalances directly in terms of known standard weights. This, in turn, makes possible the saving of much time, equipment, and labor formerly spent in indirect methods of calibration. The quartz microbalance itself is now being intensively studied as part of a broad program now being undertaken by the Bureau for the improvement of precision balances. Efforts are being made to improve the uniformity of its fabrication and to increase its capacity. The construction of the equal arm knife edge type of balance is also under study, with the object of attaining greater accuracy through improved design, use of new materials, and avoidance of troublesome temperature effects.

Another recent extension of the Bureau's weight calibration service has been to increase the certified accuracy of values for a large share of the weights in the Laboratory Classes. This increased accuracy is justified because weights are now more constant than was the case a number of years ago. Rejection of weights by the Bureau for variability with changes in atmospheric humidity together with promulgation of specifications prohibiting the use of variable adjusting material have contributed to this improvement in constancy.

In recent years, the increasing interest in scientific research in this country has brought about a corresponding increase in the number of standard weights submitted to the Bureau for calibration. The largest part of this work involves sets of weights in the following combinations of units: 5,3,2,1,1; 5,2,2,1,1; and 5,2,1,1,1. At present all computations involved in the separate calibration schemes used for each of these combinations are performed with a slide rule or a desk calculator and are then checked in detail and reviewed. Plans are under way to do a large part of this work by means of a computing machine designed to give a simultaneous solution for the values of the weights from a series of equilibrium points as observed on a balance. For this purpose, a single series of observations has been devised by means of which weights in all three of the above combinations may be calibrated. Such a scheme makes possible the construction of a machine designed for the simultaneous solution of the one series of observations and its use to compute values for sets of weights in all three combinations of units. This should largely eliminate errors of computations and result in great savings of time and effort in the Bureau's weight calibration program.

Commerce and Industry

As the custodian of the national standards of physical measurement, the National Bureau of Standards not only sets up and maintains the basic standards of length, mass, time, and other physical quantities, but also undertakes the necessary research leading to improvements and refinements in such standards and measurement methods. At the same time, the Bureau constructs, maintains, and intercompares reference and working standards which are calibrated in terms of the national standards and used in science, engineering, industry, and commerce. These services are performed for agencies of the Federal and State governments, scientific societies, educational institutions, and firms or individuals within the United States engaged in manufacturing or other pursuits requiring the use of standards or standard measuring instruments.

While the Constitution gave Congress the power "to fix the standard of weights and measures", weights used during the early days of the Republic were far from uniform. Not only was there much uncertainty as to the value of the pound, troy ounce, and other units, but the fineness of United States coinage had been questioned. To remedy the situation, a small Office of Standard Weights and Measures was set up in 1830 in the Treasury Department as part of the Coast Survey. Through this Office definite values were established for the pound and other common units. Standard weights and balances and standards of length and capacity were constructed, and accurate copies were distributed to the various States and customs houses. In this way a high degree of uniformity in standards was established and maintained. Finally, in 1901, in response to the growing need for a national scientific laboratory similar to those of Germany and Great Britain and in recognition of the high standards that had been established in weights and measures, the Congress enacted that "the Office of Standard Weights and Measures shall hereafter be known as the National Bureau of Standards".

The uniformity which the Bureau has been able to achieve in weights of all types and denominations —from 0.05-mg weights for microbalances to 10,-000-lb test weights for cargo scales—has been of great economic importance to the producing, manufacturing, processing, and distributing agencies of this country and to all purchasers of commodities. Essentially, the Congress has left to the individual States the regulation of commercial weighing devices and operations. In this work the National Bureau of Standards serves principally in an advisory capacity. However, uniformity between the States is maintained by the periodic comparison of State standards with the primary standards kept at the Bureau.

Weighing devices and weights employed by other Federal agencies, such as the weights used by the Bureau of Internal Revenue to weigh the products of distilleries or those used by the Customs Bureau to weigh cargoes, are tested and calibrated directly by the National Bureau of Standards. Through the introduction of the metric carat, based on the standard kilogram, uniformity in the measurement of the weight of gems has been achieved. Previously the many different values of the carat in use had caused much difficulty in customs work. Likewise, uniformity in the manufacture of drugs is now possible through the use of certified weights. Weights and balances tested by the National Bureau of Standards are used by the Food and Drug Administration in its regulatory work. In accordance with an Act of Congress dated March 4, 1911, the weight and fineness of coinage are verified each year through comparison with standard weights of the National Bureau of Standards.

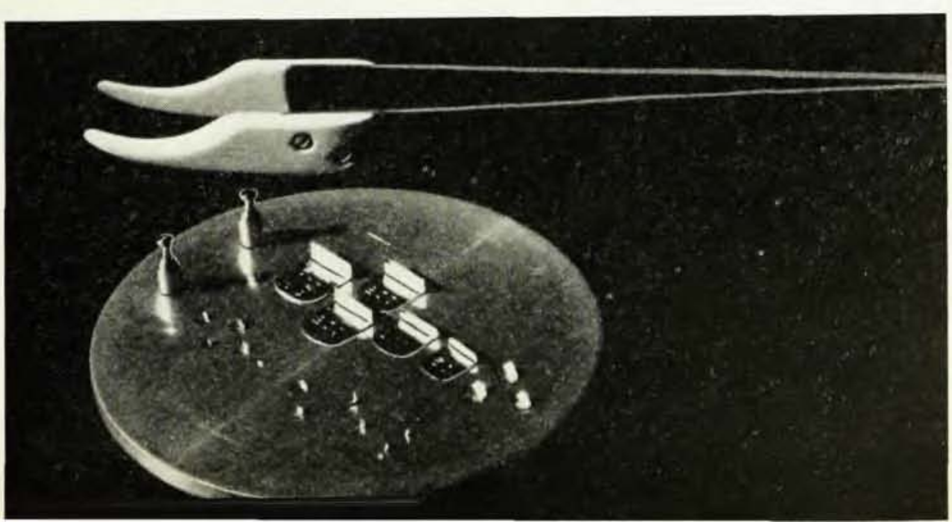
Over 30 years ago the Bureau began the testing of railway track scales in order to provide a uniform basis for the weighing of carload shipments. At that time errors in track scales ranged from 30 to 21,600 lb per 100,000, and it was not unusual for a load which was weighed at 100,000 lb in one locality to be "weighed in" at its destination as 80,000 lb. Discrepancies of this magnitude required check-weighing all along the route and, as the results of check-weighing were often not in agreement, caused much confusion. In the 34 years from 1914 to 1948, truck scales meeting tolerance requirements increased from 33 to 84 percent of the total, and a reduction in mean errors of the scales from 0.57 percent to 0.15 percent was effected.

Test weights certified by the Bureau for values of 500 lb, 1000 lb, or more are used to determine the accuracy of large-capacity vehicle scales used in industry and commerce. With the rapidly expanding use of the highways and the increasing size of truck loads, scales of this kind have become increasingly important. As the result of a survey conducted by the Bureau in 1936, which showed that the vehicle scales of this country were not sufficiently accurate, the regulatory agencies throughout the United States have greatly improved the accuracy of their vehicle-scale testing methods. Large errors in transportation charges and much expensive litigation have thus been avoided.

Office of Weights and Measures

To aid in the translation of the basic standards to the channels of industry and commerce, the Bureau established in 1947 an Office of Weights and Measures whose over-all function is to promote the extension, raise the standard of efficiency and coverage, and increase the degree of uniformity of State weights and measures supervision throughout the United States. A definite program of assistance to State and local departments of weights and measures as well as to business and industry has been set up and successfully pursued.

A large part of the activity of the Office of Weights and Measures consists of consultative services rendered through correspondence; through visits to the Office by representatives of Federal agencies, business and manufacturing concerns, and weights and measures officials; and through visits of members of the Office to weights and measures officials in their own jurisdiction. The field of inquiries is broad, embracing the drafting of new legislation; the interpretation of laws, specifications, tolerances, and regulations; the design of testing equipment; methods of test of commercial equipment; the reporting of activities in different weights and measures jurisdictions; problems of and plans for weights and measures administration; the planning and conduction of weights and measures conferences; and the training schools for State departments.



Weights used by NBS for calibration of standards for modern microbalances. Values range from 1 g down to 0.05 mg. The Bureau has recently developed methods for calibrating small standard weights below 100 mg with a precision of one or two ten-millionths of a gram.