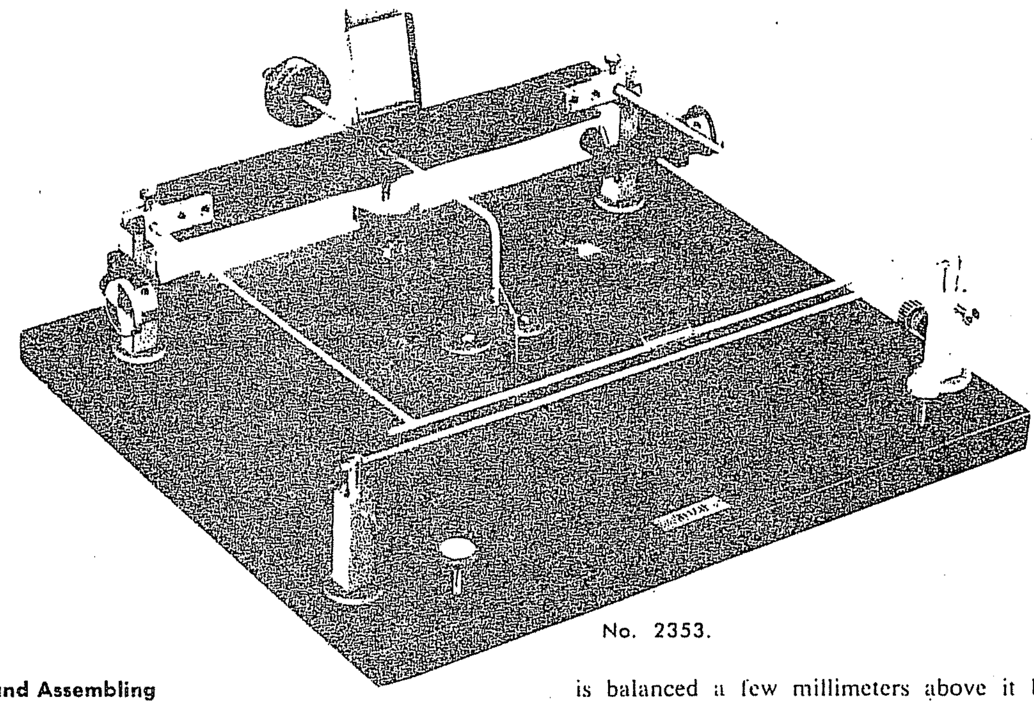
Instructions for Operating
NO. 2353 CURRENT BALANCE



No. 2353.

Unpacking and Assembling

This is a delicate instrument and should be unpacked carefully. Particular caution should be taken to avoid bending the 1/8 inch rods of the moving frame and the stationary conductor.

First remove the components taped to the underside of the base. Then remove the protective covering from the knife-edges and knife-edge bearing posts. Assemble the damping vane, mirror, and counterpoises on the channel beam. Attach the movable conductor to this beam by inserting its side arms into holes provided near the knife-edges. Mount the fixed conductor in the posts toward the front of the base. The illustration shows how the entire assembly should appear when completed. The vane should be adjusted so that it will not rub against the damping magnets or the edges of the slot in the base. Final adjustments to be made immediately before taking readings are described later.

Significance of the Current Balance

The MKS system of units, which became official in 1940, defines the ampere in terms of the force existing between two parallel conductors carrying the current. The current balance makes this fundamental measurement, just as the silver voltameter measured the obsolescent "International Ampere". The ampere is now defined as follows:

"One ampere is that unvarying current which, if present in each of two parallel conductors of infinite length and one meter apart in empty space, causes each conductor to experience a force of exactly 2 x 10^{-7} newton per meter of length."

Method of Operation

The current to be measured is to be passed in opposite directions through two parallel horizontal bars which are connected in series. The lower bar is fixed; the upper is balanced a few millimeters above it by adjusting the counterpoise. The upper bar supports a small pan into which analytical weights are placed, thereby causing the upper bar to drop down toward the lower one.

When the current is turned on and increased sufficiently, repulsion between the two bars causes the upper bar to rise to its initial equilibrium position. The position of the bar is observed by means of a mirror mounted on the beam and an auxiliary telescope and scale placed 1 to 3 meters from the mirror. The current is thus measured in terms of the weight it will lift. Weights up to about 1/2 gram are used. Weight plotted against square of the current gives a straight line, the slope of which may be varied by changing the initial adjustment of the counterpoise. Currents above 20 amperes may cause excessive heating. Either A.C. or D.C. may be used.

Usefulness

The simple straightforward design of this particular current balance has been selected because of its good pedagogical value. Thus, it is primarily a teaching instrument rather than a device for measuring current to high precision or for routine work such as calibrating ammeters.

In the laboratory the current balance provides a fundamental quantitative experiment for students. Results to within a few percent are obtainable. Like any sensitive balance, it must be used on a solid table and in a draft-free location. Its sensitivity challenges the student to use his best technique, yet its operation is rapid enough to provide adequate data in the normal laboratory period.

In the lecture room the instrument may be used for qualitative demonstration of the facts that wires carrying current attract or repel depending upon relative current direction, and that the repulsive force increases with the current. Or it can be operated as a quantitative demonstration experiment.

Principle of Operation

The force between two long parallel conductors is given from the definition of the ampere by

$$F = 2 \times 10^{-7} \cdot \frac{L}{d} \cdot I^2 \qquad \text{(Eq. 1)}$$

where F is the force in newtons (i.e., the weight in the pan converted from milligrams to newtons. By definition, a newton is the force which will impart to a mass of one kilogram an acceleration of one meter per second per second. Thus, one newton = 100,000 dynes, and a weight of one milligram = 0.98×10^{-5} newton),

L is the length of the conductors in cm (the length of the shorter bar on which the weight pan is mounted),

d is the distance between the conductor in cm when in the zero-current equilibrium position (center to center, to be measured by optical deflection, as described later).

I is the current in amperes.

Since this amounts to

$$F = k \cdot I^2 \qquad \text{(Eq. 2)}$$

where the constant

$$k = 2 \times 10^{-7} \cdot \frac{L}{d}, \qquad \text{(Eq. 3)}$$

the apparatus may be used as follows:

A. When F is plotted against I^2, a straight line should be obtained. The value of k may be determined from the slope of this line, or it may be obtained by taking the mean value of the ratio F/I^2 from observed data, which is equivalent to the slope.

B. The value of k may be computed independently, using Eq. 3, and compared with the first value.

The counterpoise may now be readjusted to give a slightly different zero-current equilibrium position, whereupon k will have a new value to be determined by methods A and B and the results compared.

Accessories suggested for use with the Current Balance when used as a student laboratory experiment:

— For D.C. operation —

D.C. ammeter, 5/10-ampere or 10/20-ampere ranges.

D.C. low-voltage power source with 10- to 20-ampere output. (Storage battery or heavy-duty power unit such as Welch No. 2606L.)

Rheostat having a resistance of a few ohms and current capacity of 15 or 20 amperes. (Welch No. 2748H carbon rheostat; or two Welch No. 2751 Slide Wire Rheostats, 2.5 ohms, 13 ampere capacity, connected in parallel are suggested.)

Set of fractional metric weights (such as Welch No. 4186)
Telescope and scale (such as Welch No. 2738)
Reversal switch (such as Welch No. 2916)

— For A.C. operation —

A.C. ammeter, 5/10-ampere or 10/20-ampere ranges

Step-down transformer with 6-volt secondary which will deliver up to 20 amperes (such as Welch No. 3673C)

Adjustable-voltage autotransformer (such as Welch No. 2608D Adjustavolt with 0 to 135-volt output)

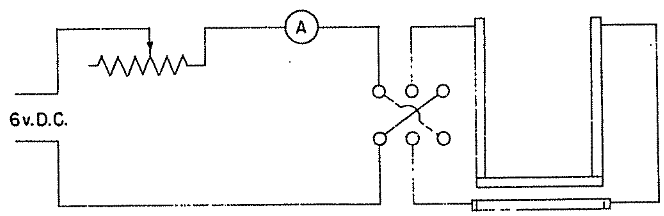
Set of fractional metric weights (such as Welch No. 4186)
Telescope and scale (such as Welch No. 2738)

Accessories suggested when used as a demonstration experiment:

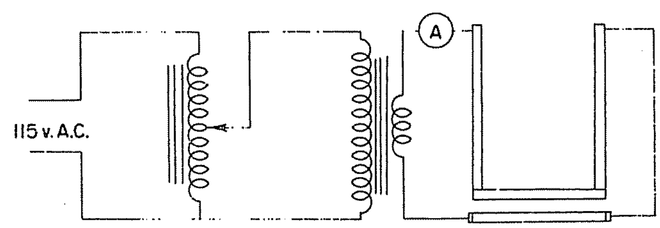
Substitute a light source (such as Welch No. 3680) to be used as an optical pointer in place of the telescope and scale in either of the foregoing lists.

Procedure

The electrical circuits for the current balance and operating accessories are shown below.



For D.C. operation



For A.C. operation

It is very important that lead wires connected to the binding posts on the balance leave them at right angles with the conductors which are part of the frame. The circuits shown provide repulsion between the two parallel bars as required in the experiment. By suitably interchanging the wires connected to the balance the bars may be made to attract each other if it is desired to show this effect.

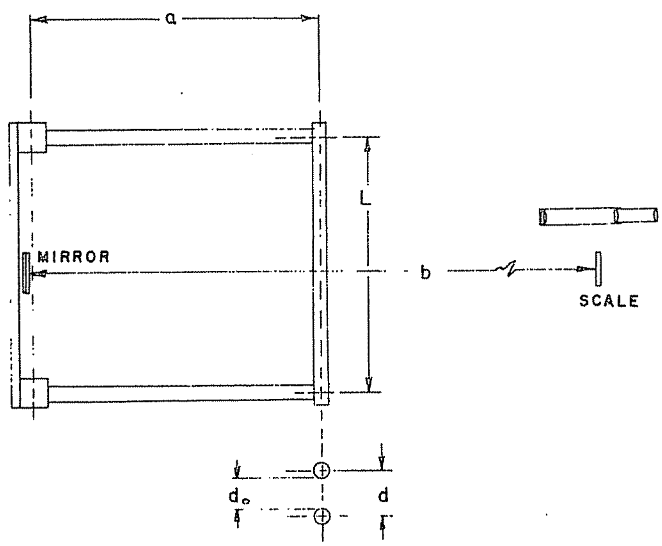
First remove the frame from the balance and clean the knife-edges, bearings, and the two parallel bars carefully to eliminate the possibility of sticky operation. If any burrs or flat spots appear to be present on the knife-edges, they should be removed with fine emery cloth or by honing. After placing the balance on a firm table and adjusting the leveling screws to make the base firmly situ-

Replace the frame and adjust the counterpoise behind the mirror until the frame oscillates freely and comes to rest with the front horizontal bar a few millimeters above the stationary bar. Adjust the counterpoise below the mirror until the period of oscillation of the frame is 1 to 2 seconds. It should come to rest in 10 to 15 seconds when the poles of the damping magnets are about 2 mm apart.

To align the two bars and to examine them for straightness, place a coin on the scale pan to bring the bars into contact, but without distortion. Thumb screws on each front post permit either end of the lower bar to be raised or lowered. Similar thumb screws on each block at the rear permit either end of the upper bar to be moved forward or backward. By careful adjustment the two bars should be aligned as accurately as can be determined by the unaided eye when viewed from the front and from the top. When viewed from the front, and with a white paper behind the bars, the two bars may appear to be slightly lacking in straightness. If this is very serious, it should be corrected by gently bending one bar or the other by hand until both appear to be straight. It is almost impossible to get them so straight that no light may be seen between them but perfect straightness is not essential to the attainment of good quantitative results. Nevertheless, the bars are rather easily bent and this inspection should be made before every trial. In general, the bars should always be handled gently and as little as necessary.

After setting up the telescope and scale at 1 to 3 meters from the mirror, remove the coin from the weight pan and record the rest point indicated by the telescope crosshairs on the telescope scale. Note that an adjustment screw behind the mirror permits the mirror's angle of tilt to be adjusted so that the telescope height may be made convenient for the observer. Engage the beam lift gently, then release it and again record the rest point. If it deviates from the first observation, the knife-edges may not be clean, the base or table may be unsteady, or the balance or telescope may have been jarred.

Measure the length L of the upper front bar from center to center of its two supporting bars extending from the knife-edges. Also measure the lever arm *(a)* or distance from knife-edge to center of the front bar at each side and take the mean.



The separation of the two bars at equilibrium is determined in the following manner. The scale reading at equilibrium is noted. Then the upper bar is depressed (by placing a coin on the scale pan) until it is in contact with the lower bar, and a new scale reading is noted. Simple geometry will show that the separation

$$d_o = \frac{Da}{2b} \qquad \text{(Eq. 4)}$$

Where D is the difference in readings,

a is the mean distance from knife-edge to bar,

b is the distance from mirror to scale.

Center to center distance, d, is obtained by adding the diameter of either rod to d_o.

To take observations, add 50 mg to the weight pan, increase the current until the scale reading indicates that the beam has returned to its equilibrium position, and read the ammeter. Repeat using successive 50-mg increments on the weight pan, plotting weight vs. current squared to detect erratic readings; or compute the ratio, which should be constant. The plotted curve should pass through the origin. For a second trial, change the counterbalance slightly to make the separation of the bars slightly different and repeat the series of readings.

When direct current is being used the earth's field will cause erroneous results. This can be eliminated by inserting a reversal switch in the circuit as shown in the diagram and taking two current readings for each load—one reading for each current direction—and using the mean current value in computations. The effect of the earth's field can also be eliminated by orienting the instrument at right angles to the earth's field.

The purpose of the beam lift is to re-locate the knife-edges to their proper positions on the knife-edge bearing posts so that the front movable conductor will always be in the same vertical plane as the fixed conductor below it The beam should be lifted each time a weight is added or removed because of the likelihood of jarring the beam during the changing of the weights. Operate the lift mechanism very carefully in raising and lowering the beam.

— Typical data —

	Trial I		Trial II	
	A.C.		D.C.	
Mirror to scale (b)	188	cm	188	cm
Diam. of bars ($2r$)	0.318	cm	0.318	cm
Lever arm (a)	21.75	cm	21.75	cm
Length of upper bar (L) ...	27.95	cm	27.95	cm
Scale reading at contact ...	12.33	cm	12.31	cm
Scale reading at equilibrium .	7.53	cm	7.8	cm
Difference, (D)	4.80	cm	4.51	cm

Trial I

F (mg)	I (amp AC)	I^2	F/I^2
50	7.1	50.4	0.99
100	10.2	104.	.96
150	12.4	154	.97
200	14.4	207	.96
250	16.2	262	.95

mean .966 mg/amp^2

From slope:

$$k_s = 0.966 \text{ mg/amp}^2 \times 0.98 \times 10^{-5} \text{ newton/mg}$$
$$= 0.95 \times 10^{-5} \text{ newton/amp}^2$$

From geometry of apparatus the computed value k_r is obtained as follows:

$$d_o = \frac{aD}{2b} = \frac{21.75 \text{x} 4.80}{2 \text{x} 188}$$

$$= .278 \text{ cm}$$

$$d = d_o + 2r = .278 + .318$$

$$= .596 \text{ cm}$$

$$k_r = 2 \text{x} 10^{-7} \cdot \frac{L}{d} \frac{\text{newton}}{\text{amp}^2}$$

$$= 2 \text{x} 10^{-7} \cdot \frac{27.95}{.596}$$

$$= 0.94 \text{x} 10^{-5} \frac{\text{newton}}{\text{amp}^2}$$

$$\text{Error} = \frac{k_s - k_r}{k_r} 100 = \frac{0.01}{0.94} = 1.1\%$$

Trial II

F (mg)		I (amp DC)	I^2	F/I^2
		6.8		
50	reversed	7.4		
	mean	7.1	50.3	.995
		9.7		
100	reversed	10.25		
	mean	9.97	99.9	1.001
		11.95		
150	reversed	12.40		
	mean	12.17	148	1.01
		13.75		
200	reversed	14.2		
	mean	13.97	195	1.03
			mean	1.009 mg/amp²

From slope $k_s = 1.009 \times 0.98 \times 10^{-5}$
$= 0.99 \times 10^{-5}$ newton/amp²

From geometry of apparatus:

$$d_o = \frac{aD}{2b} = \frac{21.75 \text{x} 4.51}{2 \text{x} 188}$$

$$= 0.26 \text{ cm}$$

$$d = d_o + 2r = 0.26 + 0.318$$

$$= 0.578 \text{ cm}$$

$$k_r = 2 \text{x} 10^{-7} \cdot \frac{L}{d}$$

$$= 2 \text{x} 10^{-7} \frac{27.95}{0.578}$$

$$= 0.965 \text{x} 10^{-5} \text{ newton/amp}^2$$

$$\text{Error} = \frac{k_s - k_r}{k_r} 100 = \frac{0.025}{0.965} = 2.5\%$$

Printed in U.S.A.
2M105769011

SARGENT-WELCH SCIENTIFIC COMPANY

Addendum to the Operating Instructions for Cat. No. 2353 Current Balance

This current balance is intended to demonstrate the force exerted by two parallel current-conducting wires. A relationship between the force and the square of the current can be shown and the slope of the curve of F vs I^2 can be compared with an independent optical measurement. Experimental data obtained from both methods should agree within 5% provided good experimental techniques are followed. It is the purpose of this addendum to suggest some sound experimental procedures that should be followed when using the current balance. However, this instrument is designed to be a teaching device and as such should not be used in calibrating meters or for analytical weighing.

The optimum mirror to scale distance should be about 1 to 1-1/2 metres. It may be necessary to adjust the tilt of the mirror to reflect the image of the scale; however, since the mirror is part of the balance, movement may change slightly the sensitivity and equilibrium point.

The knife edges were honed and checked for burrs at the factory. Further honing by the user should not be necessary and, in fact, should be avoided. Improper honing can result in deterioration of the edges. Care should be taken to protect these surfaces from accidental scratching. Never move the balance or store for a long period of time while the knife edges rest on the bearing posts. Use only the lifting arms to place and take off the balance assembly from the bearing posts.

It is suggested that weights between 20 to 200 mg be used. When setting the counterpoise and positioning the stationary conducting rod, the distance between the two rods at equilibrium should be adjusted so that the heaviest weight will not bring the rods into contact nor the distance be too great that a very large current would be needed to restore the balance to equilibrium. Never use currents above 20 A. Readings will tend to drift due to ohmic heating when using high currents.

A slight change in the equilibrium point may occur when the assembly is lifted and placed back on the bearings. Microscopic irregularities on the surfaces of both the knife edges and bearing posts contribute to a slight change in friction on the system. This change in equilibrium, however, results in less than a 0.1-mm change in the distance between the conducting rods.

When all the alignments and adjustments have been completed, a good experimental technique to follow is to record all of the data without lifting the balance between readings. Weights should be carefully placed and lifted off the pan with forceps to avoid knocking the assembly. Avoid other disturbances such as vibrations and wind currents whenever possible. Return to the equilibrium point using these procedures is very good.

G030174TC

Sargent-Welch Scientific Co., 7300 N. Linder Ave., Skokie, Ill. 60076