Operator's Manual

for

MILLIKAN OIL DROP APPARATUS

Sci-Supply model SS2438

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SS2438
MILLIKAN OIL DROP APPARATUS

1. INTRODUCTION

The model SS2438 Millikan Oil Drop Apparatus is a complete, self-contained instrument designed to reproduce Robert Millikan's famous 1909 experiment to determine the value of the elemental unit of electric charge, the charge on the electron. The apparatus consists of an illuminated test chamber, a microscope with graduated reticule, and an adjustable high-voltage DC power supply with panel voltmeter; all mounted on a compact aluminum enclosure. The apparatus is of robust construction designed to withstand the demands of school laboratory use, but yields quite accurate results.

2. TECHNICAL SPECIFICATIONS

Input power: 120vac 60Hz
Operating conditions: -10℃ to +40℃, RH <85%
Overall dimensions: 320mm x 220mm x 190mm
Weight: ~4kg
Plate voltage: 0 – ±450vdc, continuously variable from front panel
Plate separation: 5.0±0.2mm
Microscope magnification: 30x
Microscope field of view: ≥3mm
Microscope eyepiece reticule: 2.0mm in 0.5mm graduations, ±0.01mm

3. GENERAL DESCRIPTION

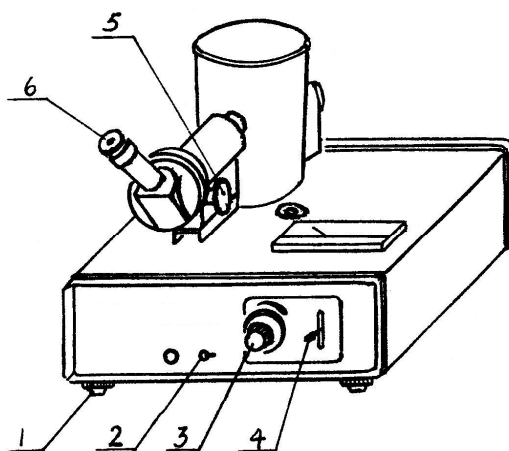The general layout of the instrument is shown in Figure 1, below.

Figure 1 – General Layout

1 - Leveling feet (3): The apparatus rests on three feet. The height of each foot can be adjusted so that the instrument sits level as indicated by a bubble level on top of the housing.
2 - Power switch: Primary power to the apparatus is switched on and off by means of this switch.
3 - Voltage adjust dial: Voltage across the plates of the oil drop chamber is adjusted by means of this dial. Voltage is indicated on a panel meter on top of the housing.
4 - Polarity switch: Polarity of the voltage across the plates of the oil drop chamber is selected by means of this switch. The switch has three positions: positive (up), off (center), and negative (down).
5 - Focusing knob: The oil drop image is focused by means of this knob.
6 - Eyepiece trim: The image of the reticule scale is brought into focus by rotating the knurled eyepiece housing.

4. DETAILED DESCRIPTIONS

The major components of the apparatus are the oil drop chamber, the microscope, and the power supply. The chamber and microscope are mounted on the top of an aluminum enclosure; the power supply is inside the enclosure.

Oil drop chamber: A cross-section of the oil drop chamber and housing is shown in Figure 2 below. The oil drop chamber consists of two parallel, circular plates, separated by an insulating spacer. The chamber is mounted inside a transparent outer housing beneath a removable oil trap and lid. The top plate of the chamber, held in place by a spring contact, is equipped with a small center hole, through which oil drops fall into the chamber between the two plates. The chamber is illuminated by a small LED lamp.

Microscope: The microscope is positioned in front of the chamber housing, so as to provide an image of the interior of the oil drop chamber. The microscope eyepiece is equipped with a reticule that divides the 2mm vertical field of view into 0.5mm increments. Vertical velocity of oil drops in the oil drop chamber is measured by timing the drops as they traverse the reticule scale.

Power supply: An internal power supply produces the voltage applied across the plates of the oil drop chamber, continuously variable from 0 – ±450vdc. Polarity is selected by means of a 3-position switch on the front panel; voltage is read from a panel meter on top of the housing. A schematic diagram of the power supply is shown in Figure 5 on page 9 of this document.
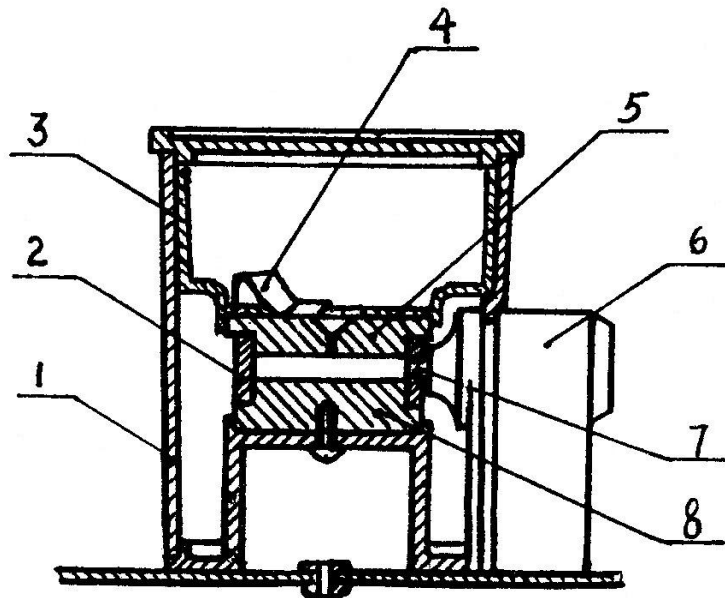

Figure 2 – Oil Drop Chamber

1 - Outer housing	5 - Upper plate
2 - Insulating spacer	6 - Illuminator
3 - Oil trap	7 - Illumination port
4 - Spring contact	8 - Lower plate

5. THEORY OF OPERATION

Suppose an oil drop with mass *m* and charge *Q* enters the oil drop chamber between the two parallel plates. With no voltage applied across the plates, the oil drop falls under the force of gravity. As shown on Figure 3, when the drop has accelerated to a velocity at which the air resistance f_1 just balances the drop's weight *mg* (buoyancy is neglected here), the drop falls at uniform velocity V_g.
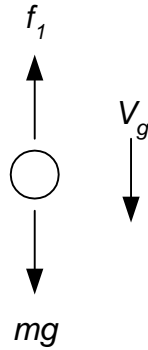

Figure 3

Thus,

$$f_1 = mg .$$ (1)

Since
$f_1 = 6\pi\eta r V_g$ according to Stokes' Law, and

$$mg = \frac{4}{3}\pi r^3 \rho g ,$$

where
η = kinematic viscosity of air (1.83x10^{-5} kg/m·s),
r = radius of oil drop in m,
V_g = downward vertical velocity in m/s,
ρ = density of oil (981 kg/m^3),
g = acceleration of gravity;

Equation (1) then becomes

$$\frac{4}{3}\pi r^3 \rho g = 6\pi\eta r V_g .$$ (1a)

Solving (1a) for the radius of the oil drop *r* yields:

$$r = 3 \cdot \sqrt{\frac{\eta V_g}{2\rho g}} .$$ (2)

With voltage U applied across the plates, an electric field E is set up between the plates. The oil drop is now influenced by an electrostatic force QE in the direction of the field. If this force is in the upward direction in opposition to the gravitational force mg and air resistance f_2 as shown in Figure 4, then at equilibrium,

$$mg + f_2 = QE, \tag{3}$$

where f_2 (or $6\pi\eta r V_E$) is the air resistance as the oil drop rises at velocity V_E.
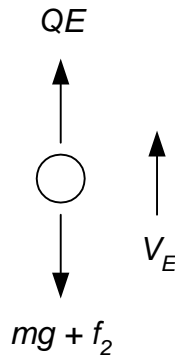

Figure 4

Combining Equations (1) and (3), the charge Q carried by the oil drop is:

$$Q = \frac{f_1 + f_2}{E} = \frac{6\pi\eta rd}{U} \cdot (V_g + V_E). \tag{4}$$

Thus far it has been implicitly assumed that air is a continuous medium. In the case of oil drops having radii on the order of 10^{-6}m as those considered here, air cannot be considered continuous. Equation (4) must therefore be corrected thus:

$$Q = \frac{6\pi\eta rd}{U} \cdot \frac{\left(V_g + V_E\right)}{\left(1 + \dfrac{8.23 \times 10^{-3}}{p \cdot r}\right)^{\frac{3}{2}}}, \tag{5}$$

where
η = kinematic viscosity of air (1.83×10^{-5} kg/m·s),
r = radius of oil drop in meters, as given in Equation (2),
d = plate separation (5×10^{-3} m),
U = voltage across the plates in volts,
V_g = downward vertical velocity in m/s (no voltage applied),
V_E = upward vertical velocity in m/s (with voltage applied),
p = atmospheric pressure in pascals.

The general procedure in this experiment will be to measure V_g, V_E, and U for a given oil drop. Drop radius r is calculated from Equation (2), and then all variables are substituted into Equation (5) to find the charge Q on the oil drop. Q is found in this way for a number of oil drops. Finally, the charge on each drop is found to be a small integer multiple of a certain number, evidently the charge e on a single electron, 1.602×10^{-19} C.

In practice, this procedure is somewhat reversed, in that the measured charge Q on each oil drop is divided by the accepted value of e to obtain a quotient close to the small integer. This quotient is then rounded to the nearest integer, and the charge Q on that particular drop is divided by this integer (evidently the number of electrons on the drop) to obtain a measured value of the elemental charge e.

6. PREPARATION FOR USE
Step 1: Place the instrument on a hard, flat workbench surface. Level the instrument by adjusting the leveling feet and observing the bubble level.

Step 2: Turn the voltage adjust control to the full counter-clockwise position, and the voltage polarity switch to the "OFF" (center) position.

Step 3: Connect a power cord to the power connector on the rear panel. Plug the power cord into a 120vac receptacle.

Step 4: Turn the power switch to the "ON" position.

Step 5: Rotate the microscope eyepiece to bring the reticule scale into focus.

Step 6: Remove the enclosure cover. Insert a straight pin into the center hole of the upper plate. Adjust the focusing knob of the microscope to bring the pin into focus. Remove the pin and replace the cover.

7. TRIAL OIL DROP SELECTION
Selection of suitable oil drops is key to obtaining good results. This requires some judgment, but only a little practice is needed to acquire the skill. Drops that are too large fall too rapidly, and will not levitate unless they carry too high a charge; thus they yield poor accuracy. Drops that are too small are excessively influenced by Brownian motion, and are easily lost. It is best to select oil drops of moderate size that rise and fall slowly but uniformly. Drops that rise 2mm in 10 to 50 seconds, with about 200v across the plates, generally yield good results.

Step 1: With the chamber cover in place, power turned on, and polarity switch in the "OFF" (center) position, spray a mist of oil into the port on the right side of the chamber housing, using a squeeze-bulb atomizer. One or two strokes of the bulb should be adequate.

Step 2: Through the microscope, observe numerous oil drops moving in an apparently upward direction. The drops are actually falling, but appear to be rising due to the inverted image of the microscope. Focus the microscope as necessary to obtain a clear image of the drops.

Step 3: After giving the large drops a few seconds to settle out, place the polarity switch in the "+" (up) position and turn the voltage control clockwise to about 200V; this will drive out any drops carrying a high charge. Observe that the remaining drops, moving at moderate speeds, reverse direction as the voltage is slowly increased and decreased.

Step 4: A single drop can now be selected and "captured" by adjusting voltage to obtain a slow rate of rise of that particular drop, and then alternately throwing the polarity switch between the "OFF" (center) and "+" (up) positions, thus causing the drop to alternately rise and fall within the field of view of the microscope.

8. MEASUREMENT
The experiment may be facilitated by two experimenters sharing the workload. For example, one may operate the apparatus and stopwatch, while the other sprays the oil, reads the voltmeter, and records data. Bear in mind that the microscope produces an inverted image, with up and down reversed.

Step 1: Produce and select a suitable oil drop per Section 7 above.

Step 2: Place the polarity switch in the "+" position and adjust voltage until the drop rises at a moderate rate. Leave the voltage control in this position through the next two steps.

Step 3: As the drop rises above the reticule scale, place the polarity switch in the "OFF" position. Start a stopwatch just as the drop crosses the upper graduation of the reticule, and stop the stopwatch as the drop crosses the lower graduation; this is time t_g. Record t_g on the data sheet.

Step 4: Place the polarity switch back in the "+" position. Start the stopwatch just as the drop crosses the lower graduation of the reticule, and stop the stopwatch as the drop crosses the upper graduation; this is time t_e. Record t_e, and the voltage U, on the data sheet.

Step 5: Repeat Steps 1 through 4. Gather data for at least five drops.

Step 6: For each drop, calculate the total charge, and the value of the elemental charge e, per Section 5 above. The average value of e for the entire data set is the final result of the experiment. Calculate the percent actual error between the average value of e and the accepted value. An example data set is shown in Table 1 on page 10 of this document.

9. USE, MAINTENANCE, AND STORAGE

One or two strokes of the atomizer bulb should be adequate to produce a number of usable oil drops. However, since this must be done multiple times per session, oil will gradually accumulate inside the oil trap. At the conclusion of each session, remove the oil trap and clean it with mild detergent and water, rinse thoroughly, and wipe dry. Remove the upper plate from beneath the spring contact, and wipe it clean with a dry, lint-free cloth; paying particular attention that the center hole is clear of oil. Reassemble. The microscope eyepiece lens may be cleaned by wiping it gently with lens tissue; but cleaning the lens should be avoided unless necessary. Store the apparatus in a cool, dry location. The eyepiece lens should be covered for storage.
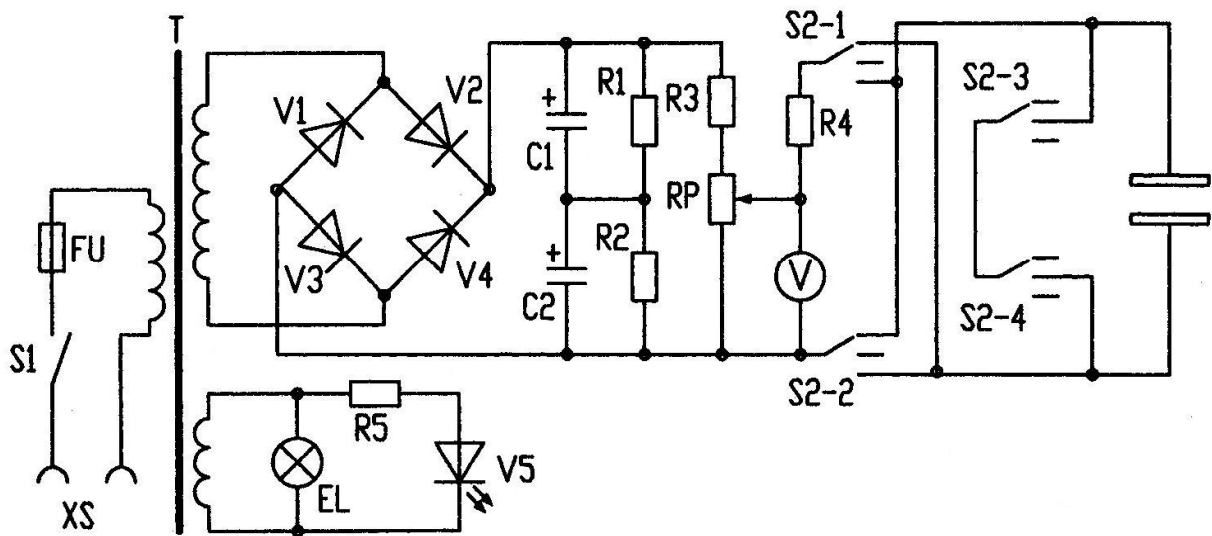

Figure 5 – Schematic Diagram

Component	Description
R1, R2	Resistor, 2.2MΩ, ¼W
R3	Resistor, 20kΩ, ½W
R4	Resistor, 5.1MΩ, 1W
R5	Resistor, 470Ω, ¼W
C1, C2	Capacitor, 10 µf, 400V
T	Transformer, pri 120v; sec 480v, 4.8v
V1, V2, V3, V4	Diode, 1N4007
V5	LED, FG114001
RP	Potentiometer, 220kΩ, 2W
S1	Switch, SPST
S2	Rotary switch, 3-position, 4-deck
FU	Fuse, 0.3A
EL	Pilot lamp, 4.8V, 2.4W
V	Panel voltmeter, 500VDC
XS	Mains cord receptacle

Trial	Without electric field		With electric field			Drop radius r (x10⁻⁶ m)	Charge on drop Q (x10⁻¹⁹ C)	Charge qty	Elemental charge e (x10⁻¹⁹ C)	Error (%)
	Fall time t_g (s)	Fall vel V_g (x10⁻⁵ m/s)	Voltage U (v)	Rise time t_E (s)	Rise vel V_E (x10⁻⁵ m/s)					
1	20.74	9.64	200	30.52	6.55	0.908	12.15	8	1.519	-5.2%
2	11.72	17.06	200	31.64	6.32	1.208	23.69	15	1.579	-1.4%
3	24.52	8.16	200	43.80	4.57	0.835	8.73	5	1.746	9.0%
4	43.66	4.58	200	83.96	2.38	0.626	3.49	2	1.745	8.9%
5	32.90	6.08	200	27.16	7.36	0.721	7.87	5	1.574	-1.7%
6	30.10	6.64	200	33.96	5.89	0.754	7.70	5	1.540	-3.8%
7	48.04	4.16	200	79.56	2.51	0.597	3.17	2	1.587	-0.9%
8	28.30	7.07	250	22.90	8.73	0.778	8.03	5	1.606	0.3%
9	13.72	14.58	150	25.84	7.74	1.117	27.76	17	1.633	1.9%
10	36.80	5.43	300	52.36	3.82	0.682	3.40	2	1.699	6.1%
							AVERAGE:		1.623	1.3%

Table 1 – Sample Data Set

d =   5.0E-03 m ρ =   981 kg/m³   g =   9.81 m/s²

L =   2.0E-03 m η =   1.83E-05 kg/m·s   e =   1.602E-19 C

p =   1.01E+05 P

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