6. Experiment of Millikan's Oil Drop

1) Adjustment of apparatus

   a. Connect AV cable between the apparatus and the monitor.
   b. Adjust the base feet while monitoring the leveling bubble to level the apparatus.
   c. Turn on power. There is no need to align the illumination light.
   d. To focus the microscope, slide the objective lens through the hole on the windscreen until the front edge of the objective lens a little bit inside of the inner surface of the windscreen. There is no need to use a focusing needle to focus the microscope.
   e. The focusing range of the microscope should not exceed 1 mm.
   f. Turn on the power of the monitor and the Millikan apparatus, after about 5 seconds, the monitor will display information of the standard scale plate, voltage (V) and time (s).
   g. Press "Timing Start/Stop" button once to trigger measurement state.
   h. Selector switch K_1 is used to select voltage polarity of upper electrode.

2) Measurement rehearsal

   a. Spray oil: spray oil drops into the oil drop channel through the hole with the sprayer while observing the oil drops on the monitor. Do not spray too much oil into the oil drop channel. Spray once or twice should be sufficient. Then, close the oil mist aperture (item 10 in Fig. 1) with the oil shutter (item 2 of Fig. 1) to avoid disturbance of ambient air flow.
   b. Select oil drops: one of the key challenges in this experiment is to select proper oil drops. If the oil drops are too large, their uniform falling speed will be too fast, resulting in more charges to be carried by these large oil drops and higher voltage to be applied to the polar plates. As a result, measurement accuracy will be decreased; on the other hand, if the oil drops are too small, they will be vulnerable to thermal motion and hence be difficult to control. In general, it is preferred to select oil drops in medium size and with slow rising or falling speed. Usually, if 200 ~ 300 V is applied to the electrodes (select "Balance" for K_2 and adjust "Balance Voltage" W to achieve this voltage), oil drops that move across 6 divisions (1.5 mm) in 8 ~ 20 s are the suitable oil drops for this experiment. Then change K_2 from "Balance" to "0 V", observe the falling speed of these oil drops, and select one proper oil drop as the measurement target. For reference, when viewing on a 10" display, the size of the oil drop image should be 0.5~1.0 mm.
   c. Time uniform motion of oil drops: select several oil drops at different moving speeds, and use the same criterion to start/stop timing by looking at the scale on the monitor.
   d. Balance oil drops: adjust the balance voltage carefully to ensure that the oil drop truly stops moving and repeat the procedure several times to ensure measurement accuracy.

3) Formal measurement

   a. Spray oil and close oil mist aperture
   b. The static method:

      (1) Press down "Balance" button, carefully balance an oil drop to be stationary by adjusting the balance voltage.

      (2) Press down "Elevation" button, bring the balanced oil drop to the 2^{nd} scale line.

Then, press down "Balance" to let the oil drop stay on the 2nd scale line.

(3) Press down "Gang Switch" and press "Timing Start/Stop" button to stop timing (if the timing is not stopped at this time. The timing readout may not be zero). Next, press down "0 V" button, the balance voltage is turned off immediately as it is synchronized with the timing button. Now timing starts, and the oil drop starts to fall down. When the same oil drop reaches the 8th scale line (l=1.5 mm), press down "Balance" button immediately. Now the same oil drop stops falling and timing stops simultaneously.

(4) Use the balance voltage and time displayed on the monitor screen to calculate the elementary charge by using equation (10).

(5) Repeat steps (1) to (4) for different oil drops (5 to 10 drops) to get accurate results.

c. The dynamic method:

(1) Select a proper oil drop and balance it by adjusting the balance voltage (K_2 is set at "Balance").

(2) Press down "Elevation" button, bring the balanced oil drop above the 2nd scale line, used as the starting line. Press "Balance" to keep the oil drop not moving.

(3) Release "Gang Switch" to void "gang" mode. Press down "0 V" button, the voltage on the electrodes is turned off, now the oil drop starts to fall down. When this oil drop reaches the starting line (i.e. the 2nd scale line), press "Timing Start/Stop" button to start timing immediately. When this oil drop reaches the ending line (e.g. the 8th scale line, l = 1.5 mm), press "Timing Start/Stop" button again to stop timing. The falling time for distance l is recorded on the screen. In the meantime, press "Balance" button to stop the same oil drop before losing it out of the viewing field. Write down the falling time t_g.

(4) Press down "Elevation" button, the same oil drop starts to rise. When the oil drop reaches the ending line (i.e. the 8th scale line), press "Timing Start/Stop" button to start timing; when the oil drop reaches the starting line (e.g. the 2nd scale line), press "Timing Start/Stop" button again to stop timing. The rising time t_e for distance l is recorded. Write down the rising time t_e and the elevation voltage V.

(5) Repeat the above measurements for different oil drops (5 to 10 drops) to calculate the elementary charges using equation (9).

4) Data Processing

The relationship between oil density and temperature is given in the table below:

T (°C /°F)	0/32	10/50	20/68	30/86	40/104
ρ (kg/m^3)	991	986	981	976	971

Take the static method as example, the formula is:

$$q = \frac{18\pi d}{V\sqrt{2\rho g}} \left[\frac{\eta l}{t_g \left(1 + \frac{b}{pa} \right)} \right]^{3/2}$$

where, $a = \sqrt{\frac{9\eta l}{2\rho g t_g}}$.

Density of oil:	ρ=981 kg×m^{-3} (at 20 °C)
Gravitational constant:	g=9.8 m×s^{-2}
Air viscosity:	η=1.83×10^{-5} kg×m^{-1}×s^{-1}
Distance of oil drop falling:	l=1.5 mm
Correction constant:	b=6.17×10^{-6} m×cmHg
Atmosphere pressure:	p=76.0 cmHg
Distance of parallel electrodes:	d=5 mm

Multiple oil drops should be measured in this experiment and the charge quantities carried by oil drops are always multiples of a minimum value. This minimum fixed value of charges is the elementary charge e as accepted as $e \cong 1.6021892\times10^{-19}$ coulombs.

When processing the experimental data, the data should be verified in a reverse order: divide the experimental data (charge quantity q) by the accepted electric elementary charge value $e\cong1.6021892\times10^{-19}$ C. The obtained quotient is a value close to a certain integer, which is the charge quantity n carried by the oil drop. Further, by dividing q by n, the obtained quotient is the experimental value of the elementary charge e.

The elementary charge can also be derived by drawing plot method. Let's assume the measured charge quantities of m oil drops are q_1, q_2, …, q_m, respectively. Considering the quantization characteristic of the charge quantity, we have $q_i=n_i e$, which is a linear equation, where n is the independent variable, q is the dependent variable, and e is the slope. Therefore, the data points of m oil drops will form a common straight line passing the origin point of the $n \sim q$ coordinates plane. If this straight line is found, the elementary charge e is the slope.

7. Experiment of Brownian Motion (optional)

1) Apparatus adjustment

   a) Move the objective barrel backward to separate it from the oil chamber, and replace the 60× objective with the 120× one;
   b) Keep "Timing Start/Stop" button pressed for 5 seconds to change the scale plate to type B (0.04 mm/div);
   c) Adjust objective barrel and balance voltage, make balance of buoyancy, electric field force and gravity for an oil drop;
   d) Record the positions (only horizontal direction) of the oil drop on the scale plate in every 5 s or 10 s. Take at least 500 data.

2) Process the data and plot $\varphi(x)\sim x$ graph

Find the maximum and minimum values from these recorded data, determine step size, group numbers, and boundary points of all groups, calculate data number in every group, list in a frequency distribution table, make frequency histogram, and finally draw distribution curve.

The following is an example of data set with a total number n= 651.

   a. Distribution table of particle displacement frequency

The step size in the following table is Δx=3, i.e. the times of displacement in range -1 to 1 is 201, in -1 to -4 is 128, … $\varphi(x)\Delta x$ equals the times in one group divided by the total times of the records.

b. Histogram of displacement frequency

Draw the histogram of displacement frequency according to the distribution table.

Displacement	Frequency v_i	v_i / n	$\sum_{i-1}^{n} v_i / n$
-15	2	0.0031	0.0031
-12	9	0.0138	0.0170
-9	23	0.0353	0.0522
-6	70	0.1075	0.1598
-3	128	0.1966	0.3564
0	201	0.3088	0.6651
3	117	0.1797	0.8448
6	65	0.0998	0.9447
9	20	0.0307	0.9754
12	13	0.0200	0.9954
15	3	0.0046	1.0000

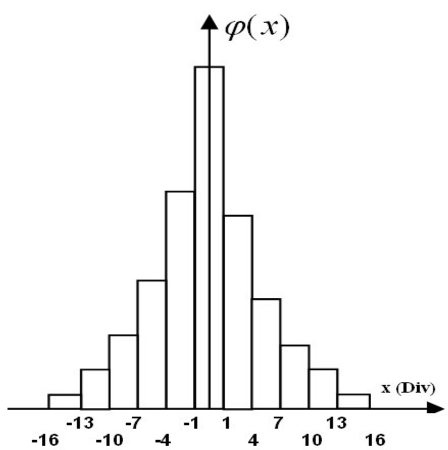


Figure 4 Histogram of displacement frequency

c. Plot straight line using normal probability paper

On the normal probability paper, the vertical axis is the distribution function $\varphi(x)$ and the horizontal axis is the particle displacement x, that is,

$$\varphi(x) = \sum_{i-l}^{i} \frac{v_i}{n}$$

where ν_i is frequency, n is the total data points, and ν_i/n is the probability of displacement x in the i^{th} group.

If a straight line is obtained on the normal probability paper, x follows the normal distribution. Use the data in the above Table to plot the graph, a straight line is obtained as shown in Figure 5 indicating that x follows a normal distribution.

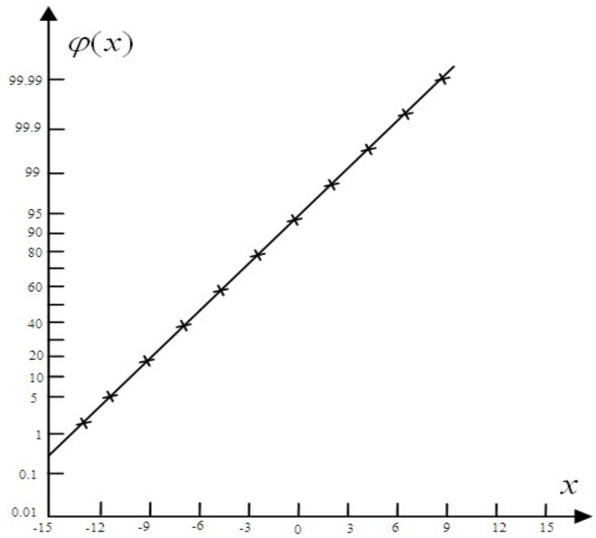
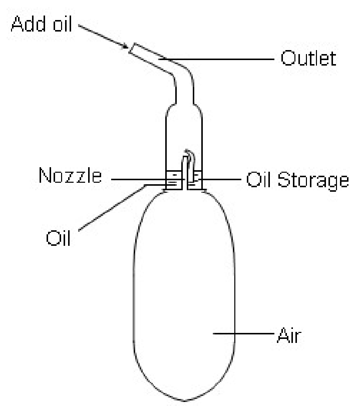


Figure 5 Displacement frequency on normal probability paper

3) Post-experiment cleaning

   After experiment, the electrodes and oil channel should be cleaned throughout with dry cloth (**Warning**: turn off the electricity before cleaning the electrodes and oil channel).

User instruction of oil sprayer



a) Suck oil into a burette or syringe from the oil bottle.
b) Add oil into the oil storage of the sprayer. Oil height 3-5 mm is enough (do not add oil to flow over the top of the small nozzle inside).
c) The outlet of the sprayer is fragile, place the outlet tip outside the oil spray aperture of the oil drop chamber with a distance 1-2 mm to spray oil drop into the chamber (do not need to insert the tip into the aperture hole).

d) If there is oil remaining in the storage, keep the sprayer in upward direction (e.g. place it in a cup) to avoid oil leakage.
e) At the end of each semester, pour out the oil from the sprayer and pinch a few times to empty the sprayer.