3B SCIENTIFIC® PHYSICS

Millikan's Apparatus

230 V, 50/60 Hz: 1018884 / U207001-230
115 V, 50/60 Hz: 1018882 / U207001-115

Instruction sheet

07/16 UD/ALF

1. Safety instructions

Millikan's apparatus conforms to the safety stipulations for electrical measuring, control and laboratory instruments as specified in DIN EN 61010 part 1. It is intended for use in dry rooms suitable for the operation of electrical equipment.

Safe operation of the equipment can be assured as long as it is used as stipulated. However, safety cannot be guaranteed if the equipment is used incorrectly or handled without due care and attention.

If it may be assumed that the equipment may no longer be operated safely (e.g. in the event of visible damage), it must be taken out of use immediately.

- Only use the equipment in dry rooms.
- Only use with the plug-in power supply provided.

2. Description

This version of Millikan's apparatus is a compact equipment set based on an experiment set-up devised by Millikan which does not require any radioactive source.

Comprising an experiment chamber kit for assembly with plate capacitor and connected oil atomiser, lighting unit with two green LEDs, measuring microscope, voltage adjustment knob and switch to set the capacitor voltage, switch for starting and stopping rise and fall time measurements and a display unit with touch screen.

Charged droplets of oil are created with the help of an oil atomiser. They will have random charge which then remains unaffected by external influences. The oil droplets are introduced into the experiment chamber from above, just as in Millikan's original set-up. Suitable oil drops are selected and their charge measured by observing them through a measuring microscope. For each of the droplets, the time it takes to rise between two chosen marks on the ocular's scale when an electric field is applied is measured, as is the time it takes to descend between the marks when the field is switched off. Alternatively the oil drops can be held stationary by an electric field of suitable strength.

The rise and descent times measured for a charged droplet, the electric field voltage setting and readings for various relevant parameters, temperature, viscosity and pressure, are displayed on the touch-sensitive screen.

3. Controls

Fig. 1 Controls

1 Adjustable feet
2 Measuring microscope on stand
3 Light intensity adjustment
4 Voltage switch U
5 Timer switch t
6 Experiment chamber
7 Display and control unit
8 Oil atomiser
9 Switch for changing plate capacitor sign
10 Co-axial power socket for plug-in power supply
11 Voltage adjustment
12 Rubber bulb
13 Focussing knobs

4. Contents

- 1 Basic apparatus with experiment chamber and display unit
- 1 Measuring microscope
- 1 Eye piece WF15x with scale
- 1 Oil atomiser
- 1 Rubber bulb with hose
- 1 Spirit level
- 1 Adjustment needle
- 1 Plug-in power supply, 12 V AC, 2000 mA
- 1 Oil for Millikan’s apparatus, 50 ml

Millikan’s apparatus 1018884 includes a plug-in power supply for 230 V (±10%), 1018882 includes one for 115 V (±10%).

5. Technical data

Plate capacitor:

Capacitor voltage:	0 – 600 V
Plate diameter:	50 mm
Plate separation:	3 mm

Measuring microscope:

Magnification of ocular:	15x
Magnification of objective:	2x
Length of scale:	10 mm
Scale divisions:	0.1 mm

General data:

Power supply:	12 V AC, 2000 mA (via plug-in supply)
Dimensions including microscope:	370x430x235 mm approx.
Weight incl. power supply:	4.3 kg approx.
Density of oil:	877 kg m^{-3} at 15°C 871 kg m^{-3} at 25°C

6. Set-up

- Set up Millikan’s oil drop apparatus on a level surface.
- Turn the vertical adjustment knob clockwise as far as it will go (see Fig. 2).
- Move the measuring microscope to the end of the stand rod on the base unit and secure it in place by means of the knurled screw at the bottom.
- Use the focussing equipment to move the measuring microscope forward as far as it will go and roughly align it in the observation window in the experiment chamber with the help of the vertical adjustment knob.
- Open the cover of the experiment chamber, place the spirit level on the uppermost plate of the plate capacitor and adjust the apparatus to its optimum horizontal alignment with the help of the adjustable feet.
- Insert the adjustment in the top plate of the plate capacitor and focus the microscope on the needle (see Fig. 3). Select a suitable light intensity and re-adjust the height of the measuring microscope by means of the vertical adjustment knob.
- Remove the needle and close the experiment chamber.
- Fill the oil atomiser to about halfway with the oil for Millikan’s apparatus and carefully slot it into the hole in the experiment chamber.
- Connect the rubber bulb to the oil atomiser by means of hose.

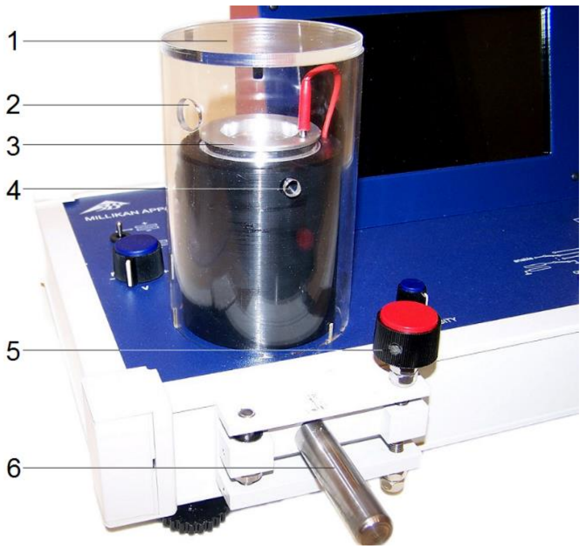


Fig. 2 Experiment chamber:
1 Cover,
2 Hole for oil atomiser,
3 Top capacitor plate,
4 Observation window,
5 Vertical adjustment knob for head of microscope,
6 Stand rod for measuring microscope

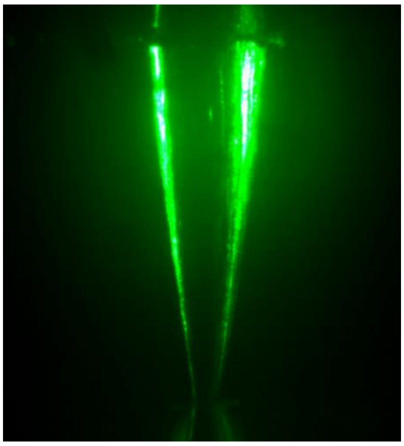


Fig. 3 View through the measuring microscope with the adjustment needle in focus

7. Operation

7.1 Starting the display and control unit

- Connect Millikan’s apparatus to the mains via its plug-in power supply.

The display and control unit will be ready to use as soon as Millikan’s apparatus has been connected up via the plug-in supply.

- Click the “Select” button (“Wählen”) to access the language menu.
- Select the required language by pressing the corresponding button and then click “Enter” to confirm. This automatically returns you to the main menu.
- Click the “Next” button in the main menu to access the measurement menu.

7.2 Optimisation of light intensity

- Look through the microscope at the measurement cell (the space between the capacitor plates) and set up a suitable light intensity. Adjust the light intensity during the measurement as needed.

7.3 Production, selection and observation of charged oil droplets

- Give a single hard squeeze on the rubber bulb to produce some oil drops and spray them into the measurement cell.
- Wait till suitable oil droplets appear in the cell. This may take a few seconds.
- Select one of the oil droplets you can see descending slowly (about 0.025 – 0.1 mm/s).
- Adjust the focus of the microscope if necessary.

Note:

The object is to produce a small number of individual oil droplets, not a large bright cloud of them since you only need to select one droplet. Squeezing the bulb more than once will mean that there are too many droplets in the measurement cell, particularly in the area between the microscope and where it is focussed. Drops there obstruct observation of droplets which are in focus. A suitable droplet will appear as a brightly lit point in the focus of the measuring microscope.

If too much oil has entered the measurement cell, it will need to be cleaned. If no droplets appear in the measurement cell, even after the bulb has been squeezed multiple times, it may be that the opening in the top capacitor plate has blocked up. Then it would need to be cleaned too.

8. Experiments

8.1 Floating method

The voltage *U* which keeps the drop floating still is determined along with the velocity v_2 at which the drop descends after the voltage is turned off

$$v_2 = \frac{x}{t_2} = \frac{S}{V \cdot t_2} . \qquad (1)$$

t_2: Time to descend, *S*: Separation of scale positions, *V*: Objective magnification (2x)

The radius r_0 and charge q_0 of the oil drop are determined from the equilibrium level of electrical force, buoyancy in air, Stokes' friction in air and the force of gravity:

$$r_0 = \sqrt{\frac{9}{2} \cdot \frac{\eta \cdot v_2}{(\rho_2 - \rho_1) \cdot g}} \qquad (2)$$

$$q_0 = 9 \cdot \pi \cdot \frac{d}{U} \sqrt{\frac{2 \cdot \eta^3 \cdot v_2^3}{(\rho_2 - \rho_1) \cdot g}} . \qquad (3)$$

η: Viscosity of air, ρ_2: Density of oil, ρ_1: Density of air, *g*: Acceleration due to gravity, *d*: Separation of capacitor plates (3 mm)

- Select the polarity of the voltage *U*, e.g. top plate "+", bottom plate "–".
- If times t_1 and t_2 have been saved from previously, they can be reset to zero by pressing "Reset".
- Describe, make, observe and select a suitable droplet as described in section 7.3.
- Set the voltage and timer switches U and t to ON and ignore the running time t_1.
- Set up a voltage which causes the selected oil drop to "float" still at a given scale marking.
- Read off the voltage *U* from the display and make a note of it.
- Set voltage switch U to OFF. This allows the observed drop to descend. Measurement of time t_2 starts automatically.
- Set timer switch t to OFF as soon as the drop has reached a scale position decided in advance. This stops the measurement of t_2.
- Read off the time t_2 from the display and make a note of it along with the separation of the two scale positions.
- Repeat the measurement as often as possible for different oil drops, changing the sign of the voltage *U* as you do so.

8.2 Rising/falling method

For a selected value of voltage *U*, the velocity with which a drop rises v_1 and the velocity with which it descends v_2 are both determined

$$v_1 = \frac{x}{t_1} = \frac{S}{V \cdot t_1} , \; v_2 = \frac{x}{t_2} = \frac{S}{V \cdot t_2} . \qquad (4)$$

t_1: Rise time, t_2: Fall time, *S*: Separation of scale position, *V*: Objective magnification (2x)

The radius r_0 and charge q_0 of the oil drop are determined from the equilibrium level of electrical force, buoyancy in air, Stokes' friction in air and the force of gravity:

$$r_0 = \sqrt{\frac{9}{2} \cdot \frac{\eta \cdot v_2}{(\rho_2 - \rho_1) \cdot g}} \qquad (5)$$

$$q_0 = 9 \cdot \pi \cdot \frac{d}{U} \cdot (v_1 + v_2) \cdot \sqrt{\frac{2 \cdot \eta^3 \cdot v_2}{(\rho_2 - \rho_1) \cdot g}} . \qquad (6)$$

η: Viscosity of air, ρ_2: Density of oil, ρ_1: Density of air, *g*: Acceleration due to gravity

- Select the polarity of the voltage *U*, e.g. top plate "+", bottom plate"-".
- If times t_1 and t_2 have been saved from previously, they can be reset to zero by pressing "Reset".
- Describe, make, observe and select a suitable droplet as described in section 7.3.

- Set voltage switch U to ON. Set up a voltage U at which the oil drop slowly rises past a selected initial scale marking in the top part of the measurement cell.
- Move switch U to OFF so that the oil drop starts to descend again.
- Set switch t to ON as soon as the oil drop has returned to the first position you chose. This starts the measurement of time t_2.
- Set switch U to ON as soon as the drop passes a selected scale marking in the lower part of the measurement cell, thus causing the drop to start rising again. Measurement of time t_2 stops and measurement of time t_1 starts automatically.
- Set switch t to OFF as soon as the oil drop has returned to the first position you chose. This causes the measurement of time t_1 to stop.
- Set switch U back to OFF.
- Read off the times t_1 and t_2 as well as the voltage U (“Previous Voltage”) from the display and make a note of them along with the separation of the scale markings.
- Repeat the measurement for as many different oil drops as possible and using a variety of capacitor voltages. Change the sign of the voltage U as you do so.

8.3 Correction for Stokes friction

Very small radii r_0 are of the same order of magnitude as the mean free path of air molecules. This requires a correction for the Stokes force of friction. The corrected radius r and charge q are then given by:

$$r = \sqrt{r_0^{\,2} + \frac{A^2}{4}} - \frac{A}{2} \quad \text{where} \quad A = \frac{b}{p} \qquad (7)$$

b = 82 µm·hPa = constant, p: air pressure

$$q = q_0 \cdot \left(1 + \frac{A}{r}\right)^{-1{,}5} . \qquad (8)$$

r_0 is given by equations (2) or (5) and q_0 by equations (3) or (6).

8.4 Parameters relevant to the results

Temperature, air pressure and viscosity of air are measured or calculated with the help of built-in sensors and are displayed on the screen.

Density of oil:
877 kg m^{-3} at 15°C
871 kg m^{-3} at 25°C

Density of air:
1.293 g m^{-3} at 0°C and 1013.23 hPa

8.5 Evaluation

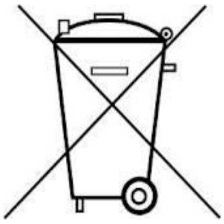
- The charges of the oil drops can be determined using equation (8).

The charges derived from measurement are divided by a whole number n such that the resulting values have the least possible spread around their average, which represents an estimate of the elementary charge of electrons or protons. Standard deviation provides a measure of the spread. The result is more meaningful the more measurements are recorded, i.e. the greater the size of the sample and the fewer the number of values of charge on the oil drops (recommendation: $n < 10$).

9. Storage, cleaning and disposal

- Keep the equipment in a clean, dry and dust-free place.
- Before cleaning the equipment, disconnect it from its power supply.
- Do not clean the unit with volatile solvents or abrasive cleaners.
- Use a soft, damp cloth to clean it.
- The packaging should be disposed of at local recycling points.

Should you need to dispose of the equipment itself, never throw it away in normal domestic waste. If being used in private households it can be disposed of at the local public waste disposal authority.



- Comply with the applicable regulations for the disposal of electrical equipment.