Related topics

Electric field, electric field strength, electric flux, electrostatic induction, electric constant, surface charge density, dielectric displacement, electrostatic potential.

Principle and task

A small electrically charged ball is positioned at a certain distance in front of a metal plate lying at earth potential. The surface charge on the plate due to electrostatic induction together with the carged ball forms an electric field analogous to that which exists between two oppositely charged point garges (Fig. 2).

The electrostatic force acting on the ball can be measured with a sensitive torsion dynamometer.

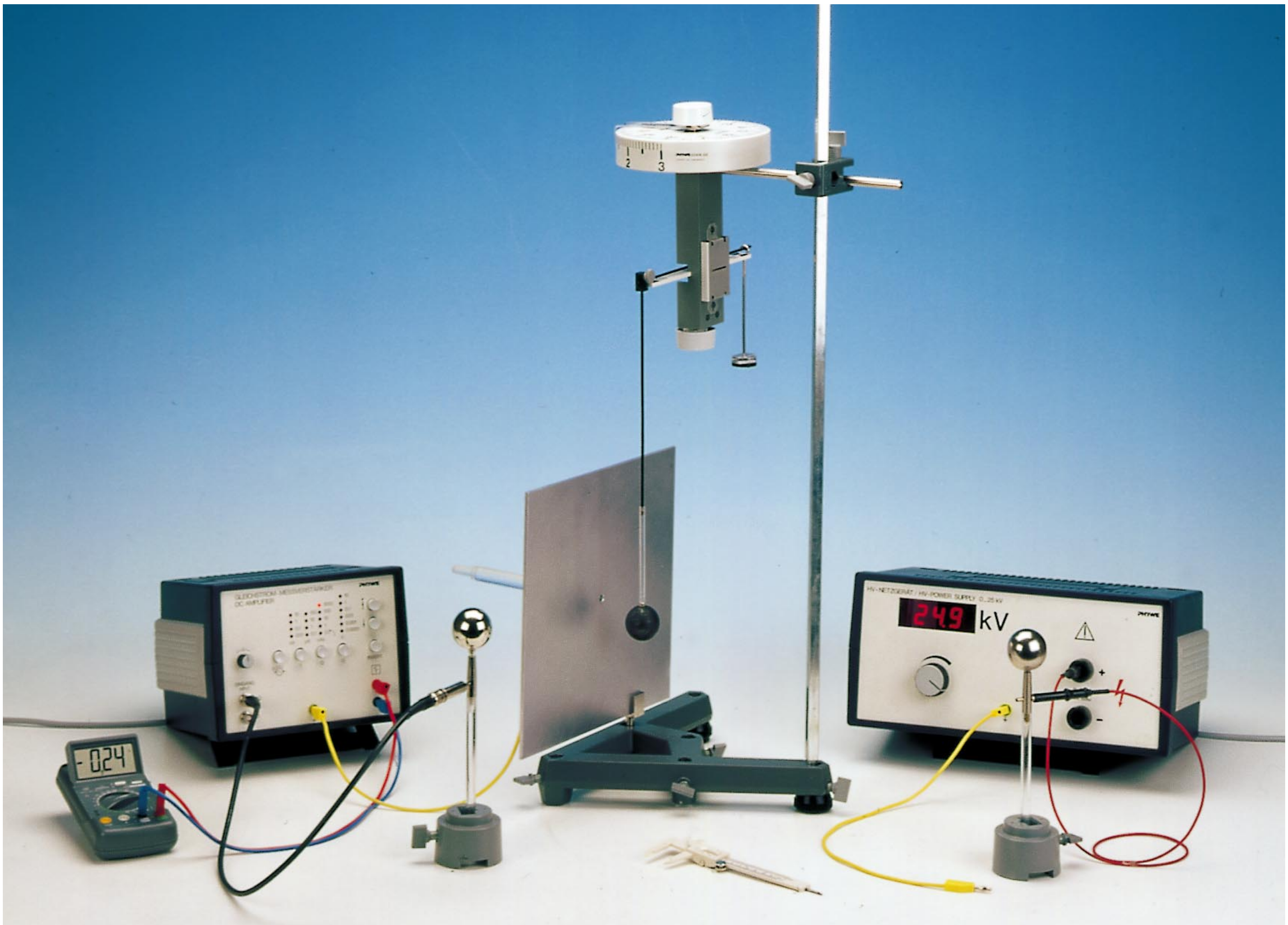
Equipment

Plate capacitor, 283×283 mm	06233.02	1
Insulating stem	06021.00	2
Conductor ball, d 40 mm	06237.00	2
Conductor spheres, w. suspension	02416.01	1
Torsion dynamometer, 0.01 N	02416.00	1
Weight holder f.slotted weights	02204.00	1
Slotted weight, 1 g, natur. colour	03916.00	4
DC measuring amplifier	13620.93	1
Power supply, high volt., 0-25 kV	13671.93	1
Digital multimeter	07134.00	1
Connecting cord, 50 KV, 1000 mm	07367.00	1
Screened cable, BNC, l 1500 mm	07542.12	1
Adapter, BNC socket - 4 mm plug	07542.20	1
Connecting cord, 500 mm, red	07361.01	3
Connecting cord, 750 mm, red	07362.01	1
Connecting cord, 750 mm, blue	07362.04	1
Connecting cord, 1000 mm, green-ye	07363.15	2
Support base -PASS-	02005.55	2
Right angle clamp -PASS-	02040.55	1
Support rod -PASS-, square, l = 1000 mm	02028.55	1
Holder for U-magnet	06509.00	1

Problems

1. Establishment of the relation between the active force and the charge on the ball.
2. Establishment of the relation between force and distance, ball to metal plate.
3. Determination of the electric constant.

Fig. 1: Experimental set-up for measurement of the electrostatic force of attraction acting on the ball.



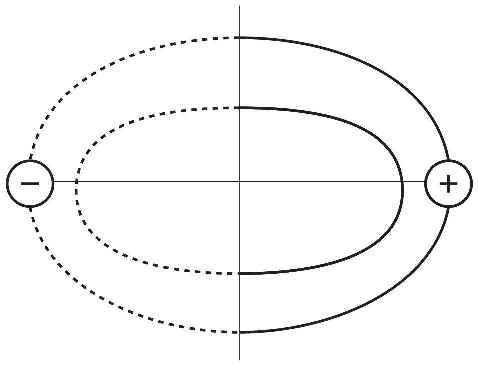


Fig. 2: Principle for Coulomb's law and image charge.

Set-up and procedure

1. The experimental set-up for measurement of the electrostatic force is shown in Fig. 1.
   Set the desired force on the dynamometer for a given distance between ball and plate, charge the ball and wait until the charge has dropped far enough for the dynamometer to return to the starting position, then immediately measure the charge. The DC-amplifier is set in the charge measuring mode (press "Q" button), scale 1–10 uAs.

2. Repeat this procedure for different distances between conductor ball and conductor plate.
   Limit the distances to the range between 4 cm and 8 cm since, when the distances are smaller, the charge on the conductor ball is largely transferred to the plate (electrostatic induction) and, when the distances are larger, the electric field is distrubed by the surroundings and the edges of the condenser plate.

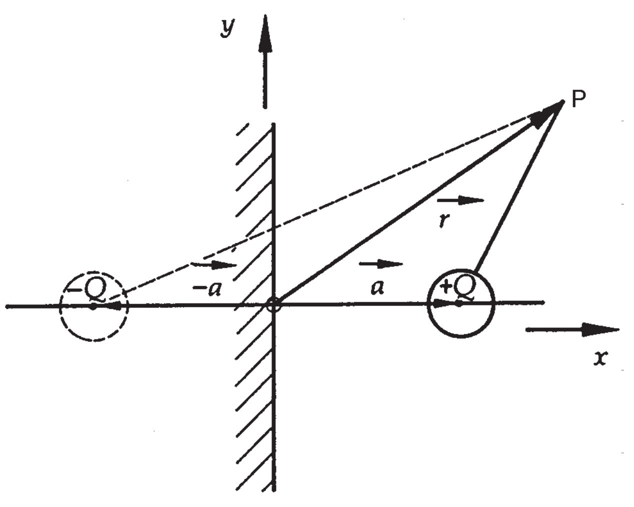


Fig. 3: Geometrical relationship in the plate/charge and image charge/charge system.

Theory and evaluation

In accordance with Fig. 3 the electrostatic potential φ in the vicinity of two point charges of opposite polarity in the point P defined by $\vec{r}$ is

$$\varphi(\vec{x}) = \frac{Q}{4\pi\varepsilon_0 |\vec{r} - \vec{\alpha}|} - \frac{Q}{4\pi\varepsilon_0 |\vec{r} + \vec{\alpha}|}$$

$$= \frac{Q}{4\pi\varepsilon_0 \sqrt{(x-\alpha)^2 + y^2}} - \frac{Q}{4\pi\varepsilon_0 \sqrt{(x+\alpha)^2 + y^2}}$$

where Q represents the amount of charge and ε_0 the electric constant. To prove this spatial potential distribution in the plate/ball system, it is advisable to relate the electrostatic potential to a certain locus (e.g. $\frac{1}{2}\vec{\alpha}$). We obtain

$$\varphi(\vec{r}) = \frac{3}{4}\varphi\left\{\frac{1}{2}\vec{\alpha}\left(\frac{\alpha}{\sqrt{(x-a)^2 + y^2}} - \frac{\alpha}{\sqrt{(x+\alpha)^2 + y^2}}\right)\right\}$$

In an example of measurement there is a potential of 1000 V with respect to earth potential on the conductor baal. One obtains for the reference point in this case.

$$\varphi\left(\frac{1}{2}\vec{\alpha}\right) = 175 \text{ V.}$$

See experiment 4.2.01 "Electric fields and potentials in the plate capacitor".

From

$$\vec{E}(\vec{r}) = -\operatorname{grad}\frac{-Q}{4\pi\varepsilon_0 |\vec{r} + \vec{\alpha}|}$$

the electrostatic field produced by the image charge becomes

$$\vec{E}(\vec{r}) = -\frac{-Q}{4\pi\varepsilon_0 |\vec{r} + \vec{\alpha}|^3}(\vec{r} + \vec{\alpha}).$$

Hence the electrostatic force acting on the charge at the locus $y = 0$, $x = $ a is

$$\vec{F} = Q\left(\vec{E}(\vec{\alpha})\right)$$

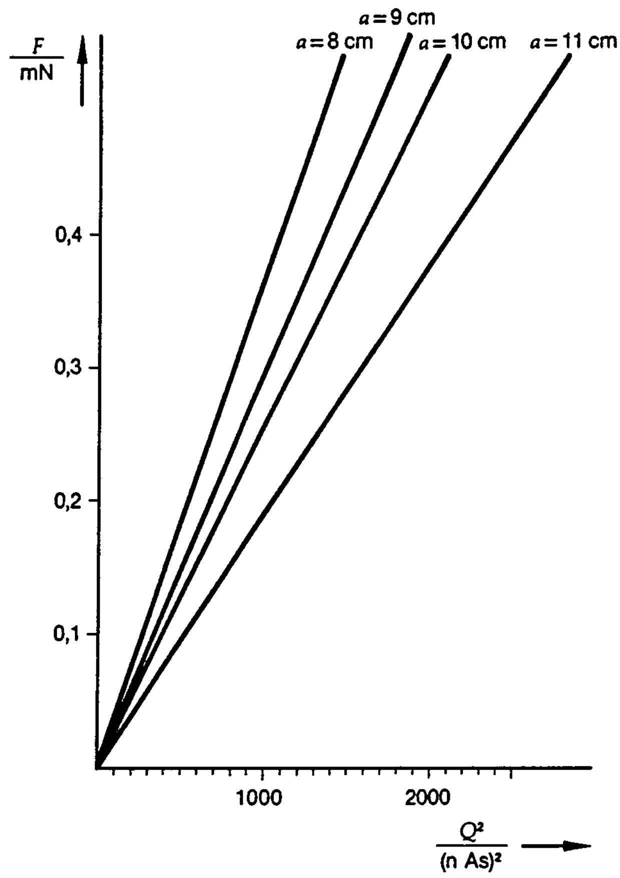
$$= -F\frac{\vec{\alpha}}{\alpha}$$

with

$$F = \frac{Q}{16\pi\varepsilon_0 \alpha^2}.$$

The pairs of values of force and charge found for different distances α between the conductor ball and the condenser plate in a mesurement example are shown in Fig. 4.

Fig. 4: Relationssship between electrostatic force F and charge Q for various distances α between ball and plate.



The regression straight lines to the measurement values in Fig. 4 with the power statements

$$F = A_\alpha \, Q^{B\alpha}$$

yield

$\frac{\alpha}{\text{cm}}$	8	9	10	11
B_α	2.21	1.93	2.40	2.02

The force F is therefore proportional to the square of the charge:

$$\frac{F}{Q^2} = A_\alpha .$$

The proportionality factor A_α obtained from Fig. 4 by measuring the slope is a function of the distance α between condenser plate and ball (Fig. 5). The regression straight line to the values in Fig. 7 with the power statement

$$A_\alpha = \frac{1}{16\,\pi\,\varepsilon_0}\;\alpha^B$$

yields the exponent

$$B = -\,2.00 = 0.2$$

Therefore

$$\frac{F}{Q^2} \sim \frac{1}{\alpha^2}\,.$$

The proportionality factor yields the value for the electric constant

$$\varepsilon_0 = \frac{Q^2}{16\,\pi\,\alpha^2\,F} = 8.4 \cdot 10^{-12}\,\frac{\text{As}}{\text{V cm}}\,.$$

(Value in literature: $= 8.859 \cdot 10^{-12}$ As/Vm).

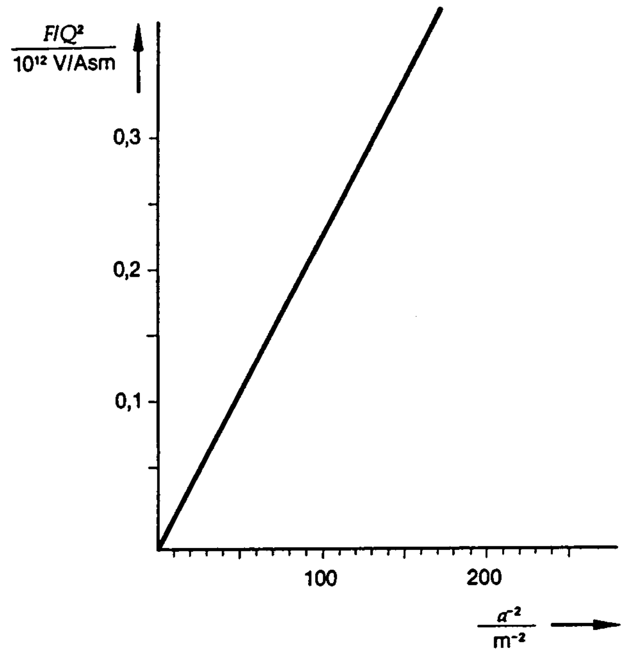


Fig. 5: Quotient of force F and square of the charge Q corresponding to the slopes of the straight lines in Fig. 6 as a function of the distance α between ball and plate.