

Preview of Period 10: Electric Charge and Force

10.1 Electric Charge and Forces

What happens when you place a negatively charged rod near an object?

How do charges cause objects to move?

10.2 Conductors, Insulators, and Separation of Charge

How can you make a bulb light using a plastic rod and a soda can?

How do Leyden jars store charge?

10.3 Storing Charge on Capacitors

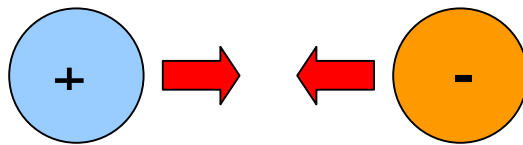
How do capacitors store charge?

Electrical Charge

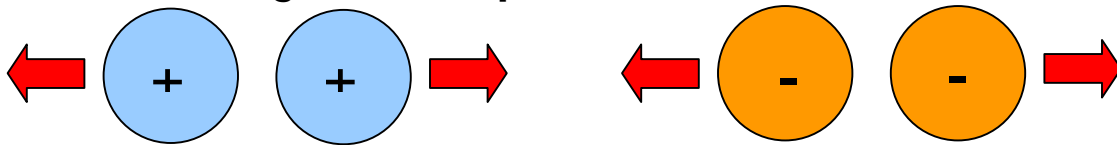
Charge come in two types:

negative and **positive**.

Charges of opposite signs (one negative and one positive) attract one another



Charges of the same sign (both positive or both negative) repel one another.



- Uncharged objects have equal amounts of positive and negative charge.
- The attraction or repulsion between charged objects with an excess of positive or negative charge results in an **electrical force** on the objects.

Electrical Charge, Continued

- The symbol for charge is Q
- The unit of charge is a coulomb (coul)

How large is a coulomb?

- When you rub the rod with the foam, you place about one microcoulomb (10^{-6} coul) of negative charge on the rod

How do charges move?

- Negative charge (electrons) can move freely through **electric conductors**. Most metals are good electric conductors.
- **Electric insulators** prevent the flow of charges. Good insulators include glass, plastic, rubber, and **dry** air.

Electrical Forces and the Four Fundamental Forces

Fundamental Forces

Gravitational

Electromagnetic = **Electrical** + Magnetic

Weak Nuclear

Strong Nuclear

- ◆ Gravitational forces act between masses.
- ◆ **Electrical forces act between charges.**
- ◆ Magnetic forces act between moving charges.

Compare the equations for gravitational and electrical force:

$$F_{grav} = \frac{G M_1 M_2}{D^2}$$

$$F_{elect} = \frac{k Q_1 Q_2}{D^2}$$

Q_1 and Q_2 = charge on the objects (in coul)

D = distance between objects (in meters)

k = a constant = 8.99×10^9 N m²/coul²

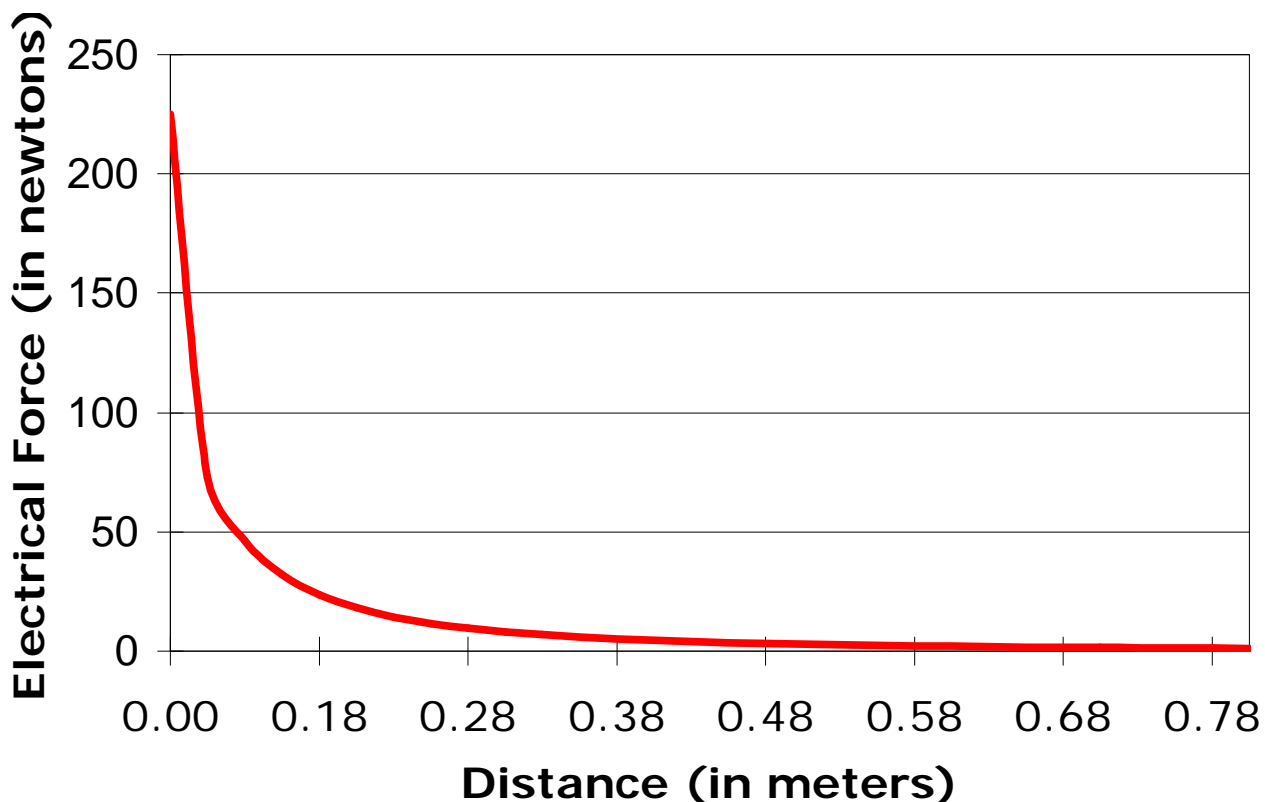
Electrical Force Equation

- ◆ The strength of the electrical force decreases as the distance between the charged objects increases.
- ◆ In fact, the force decreases as the **square of the distance** between charged objects

$$F_{elect} = \frac{k Q_1 Q_2}{D^2}$$

- ◆ The graph illustrates the relationship between force and distance squared.

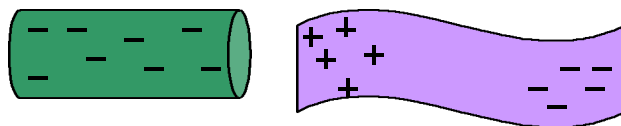
Electrical Force versus Distance between Two Charged Objects



Act. 10.1: Electric Charge and Electric Conductors

- When a rod with negative charge is placed near an uncharged piece of metal, electrons in the metal are repelled by the negative charge on the rod.
- The negative electrons move away from the negative rod.
- The metal now has more positive charge at the end near the rod and more negative charge at the end away from the rod.
- The negative rod attracts the nearer positive charge more strongly than it repels the farther negative charge and an attractive force results

A Charged Rod Near Metal

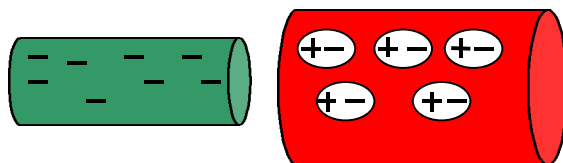


Negative charges on the rod attract positive charges in the metal and repel negative charges.

Act. 10.1: Electric Charge and Electric Insulators

- When a rod with negative charge is brought near an insulator, the **electrons in the insulator cannot move** because each electron is bound to its individual atom.
- The atoms deform slightly so that the negative charges lean away from the negative rod and the positive charges lean toward it
- The negatively charged rod exerts an attractive force on one end of the insulator.

A Charged Rod Attracts a Wooden Dowel

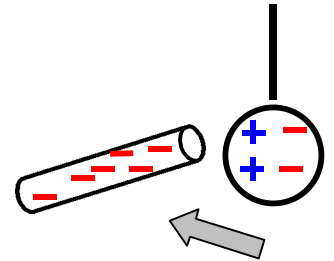


Negative charges on the rod deform atoms in the dowel, attracting positive charges and repelling negative charges.

Act. 10.1.a: Electric Charges Exert Forces

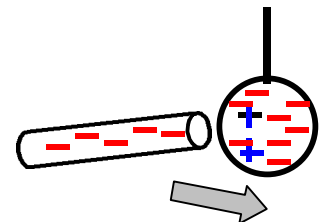
Bring the charged rod near the pith ball.

1. The neutral pith ball is attracted to the negatively charged rod.
2. Negative charges on the rod repel the negative charges on the pith ball.
3. The side of the pith ball closer to the rod is positively charged.
4. The pith ball is attracted to the rod.



Touch the pith ball with the charged rod.

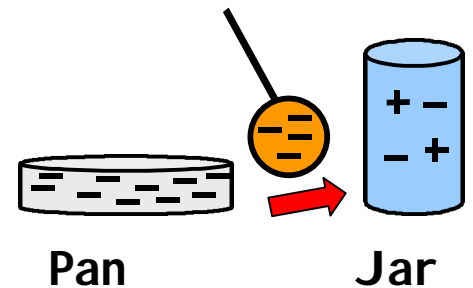
1. Negative charges from the rod give the pith ball a net negative charge.
2. The negatively charged rod repels the negatively charged pith ball.
3. The pith ball moves away from the rod.



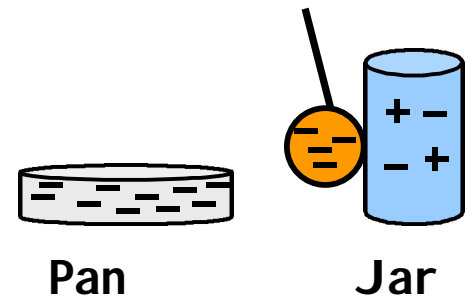
Electrostatic Oscillator Work?

Rubbing the blue foam places a negative charge on the foam and the foil pan.

Why does the foil ball move away from the negatively charged pan?

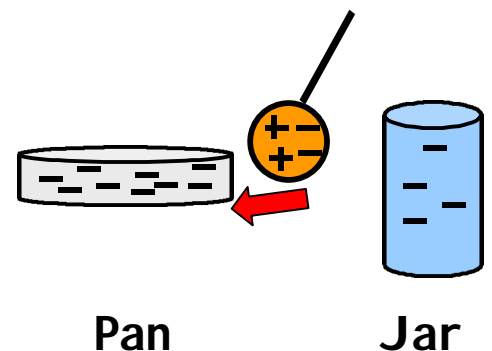


What happens to the charges on the foil ball when it touches the metal Leyden jar?



After the foil ball touches the Leyden jar, the foil ball has no net charge.

Why is the foil ball attracted to the negatively charged pan?



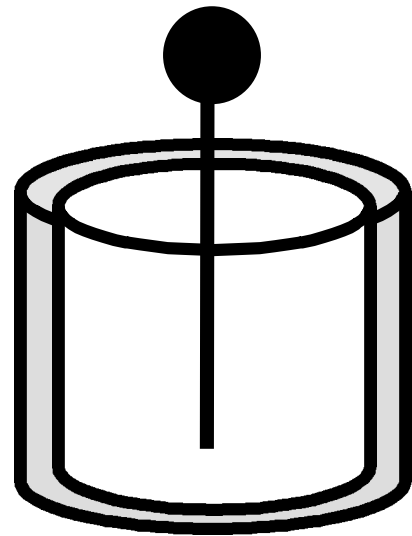
Act. 10.3: Conductors, Insulators, and Separation of Charge

Place negative charge on a can by sliding the charged plastic rod along the can.

Use the tin can voltmeter to measure the voltage of the charges.

Is the neon bulb the **brighter** when touched to

- ◆ one charged Leyden jar? or
- ◆ two charged Leyden jars separated by a plastic liner?



Potential Energy and Voltage

Electrical forces store **electrical potential energy** when we do work to push charges of the same sign together.

Electrical potential energy is converted into electrical energy when the charges are allowed to move apart.

$$E_{pot} = Q V$$

E_{pot} = the potential energy (in joules)

Q = the amount of charge (in coulombs)

V = the voltage (in volts)

Voltage = the potential energy per charge.

Voltage is measured in volts (V)

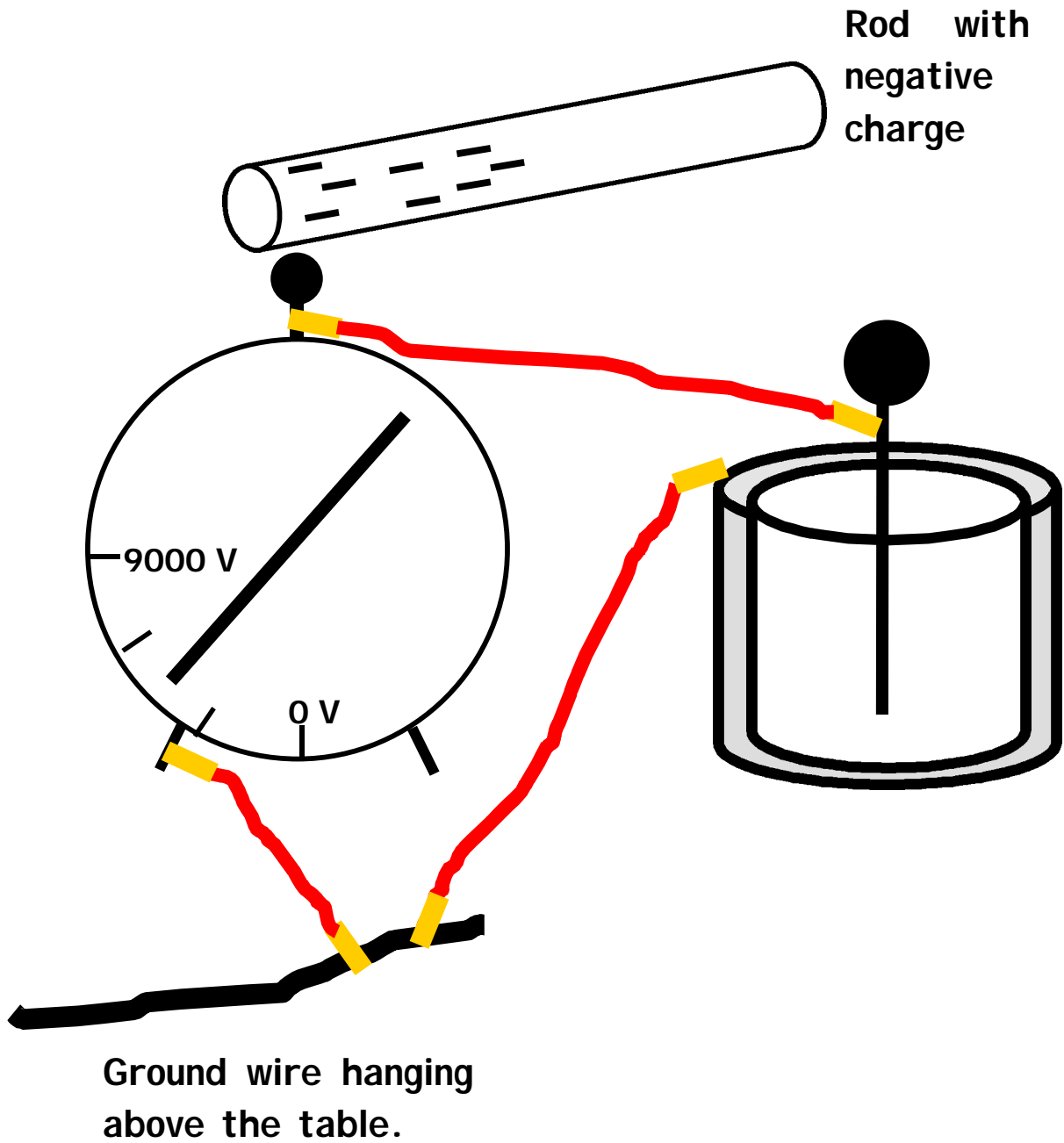
1 volt = 1 joule of energy/1 coulomb of charge

Compare electrical and gravitational potential energy

Gravitational potential energy = $M (g h)$

Electrical potential energy = $Q (V)$

Act. 10.4: Tin Can Voltmeter



Act. 10.5: Storing Charge on Capacitors

- ◆ A **capacitor** is a device that stores charge.
- ◆ The charge-holding capacity of a capacitor is called its **capacitance**.
- ◆ The unit of capacitance is the **farad**.
- ◆ The greater the capacitance, the more charge Q can be stored at voltage V

$$Q = C V$$

Q = charge (in coulombs)

C = capacitance (in farads)

V = voltage (in volts)

(Example 10.2)

A 0.5 farad capacitor stores 5.0 coulombs of charge. At what voltage is the charge?

$$V = \frac{Q}{C} = \frac{5.0 \text{ coul}}{0.5 \text{ farad}} = 10 \text{ volts}$$

Energy Stored in Capacitors

The energy stored in a capacitor is:

$$E_{cap} = \frac{1}{2} Q V_{final}$$

The equation uses the **average voltage of the charges**. Initially, the voltage of the charges is very low. As the capacitor fills, the voltage increases. The **factor of ½** in the equation comes from taking **the average of the initial and final voltage** of the charges.

(Example 10.3)

How much energy does a 1.0 farad capacitor store when it is charged to 5.0 volts?

First, find the charge, Q , from the capacitance and the voltage.

$$Q = C V = (1.0 \text{ farads}) \times (5.0 \text{ volts}) = 5.0 \text{ coul}$$

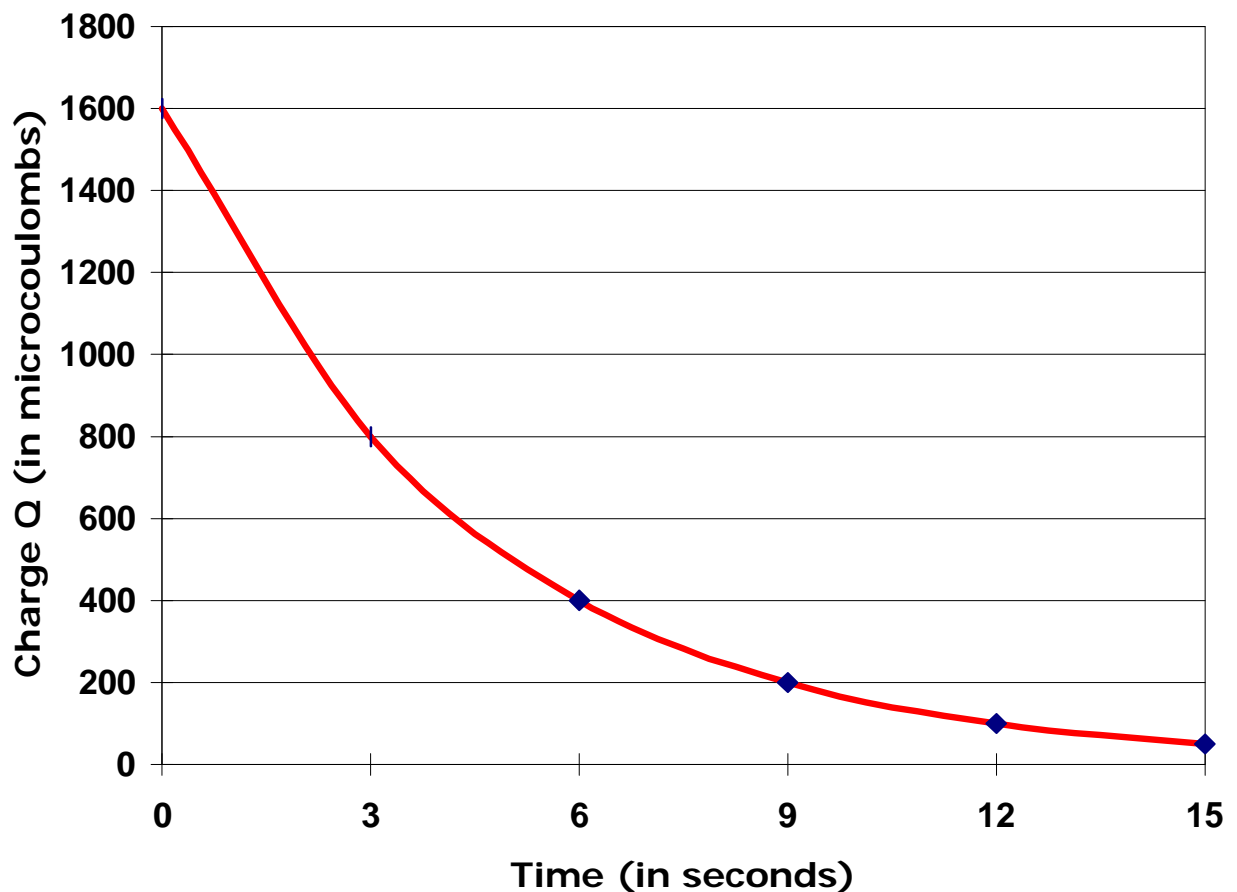
Next, use the capacitance equation

$$\begin{aligned} E_{cap} &= \frac{1}{2} Q V_{final} = \frac{1}{2} (5 \text{ coul}) \times (5 \text{ volts}) \\ &= 13 \text{ joules} \end{aligned}$$

Capacitor Discharge

- Capacitors discharge their stored charge exponentially.
- The amount of charge in the capacitor decreases by $\frac{1}{2}$ during each time period.
- The time it takes for a capacitor to discharge $\frac{1}{2}$ of its charge is called a **half-life**.

Discharge of a Capacitor versus Time



Period 10 Summary

10.1: Charged ions occur when electrons are removed from neutral atoms. Charges come in two types: positive and negative.

- ◆ Charges of the same sign (+),(+) or (-), (-) repel each other.
- ◆ Charges of opposite sign (+), (-) attract.
- ◆ Objects with equal numbers of positive and negative charges are neutral.

10.2:Electrical forces result from the repulsion between same sign charges and the attraction between opposite sign charges.

10.3:Conductors, such as metals, allow charges to flow through them.

Insulators, such as glass or rubber, prevent charge flow.

Insulators can be used to separate positive and negative charges.

Period 10 Summary, Continued

10.4: Electrical potential energy is stored when work is done to push same sign charges together or pull opposite sign charges apart. The electrical potential energy is

$$E_{pot} = Q V$$

Voltage (V) is the amount of electrical potential energy per charge.

10.5: Capacitors store electric charge. Their charge-holding capability is called capacitance, C .

Capacitance is measured in units of farads.

$$C = Q / V$$

This equation can be used to define electric charge, Q , in terms of capacitance and voltage.

$$Q = C V$$

The energy stored in a capacitor =

$$E_{cap} = \frac{1}{2} Q V_{final}$$

Period 10 Review Questions

- R.1** How do you know there is more than one type of electric charge? Give evidence from your class activities
- R.2** Is voltage the same as energy? If not, how do they differ?
- R.3** Do you think we will someday have electric cars powered by capacitor energy storage? What difficulties might battery-powered electric cars have?
- R.4** Why does a Leyden jar capacitor have a larger capacitance than a can of the same size?
- R.5** Why do you use a battery, rather than a charged rod, to charge up a 1.0 farad capacitor?

R.6 Fill in the table with the symbol, the units, and the unit abbreviation.

Quantity	Symbol	Units	Unit Abbreviation
Electrical Force	F	newton	N
Electric Charge	Q	coulomb	coul
Voltage	V	volt	V
Capacitance	C	farad	farad
Electrical Potential Energy	E_{pot}	joule	J
Power	P	watt	watt
Work	W	joule	J

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