

Exercise walk-through

# 10.4

## Dielectrics

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AP Physics C: Electricity and Magnetism

# Dielectrics

A **dielectric** is an insulator that **polarizes**, building an internal field that opposes the applied one.

## Sliding it in

$$C = \kappa C_0$$

the **dielectric constant**  $\kappa$  – and the field between the plates drops.

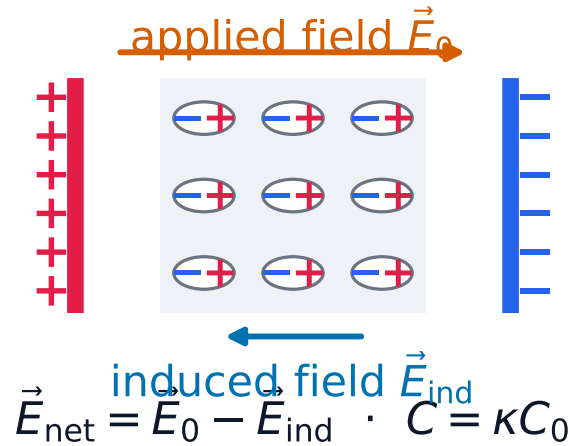
**Constant charge:**  $V$  and  $U$   
*drop*

**Constant voltage:**  $Q$  and  $U$   
*rise*

$\kappa = 3$ :

$C_0 = 5 \rightarrow 15 \mu\text{F}$ .

# A polarized dielectric creates an internal field



dielectric:  $C = \kappa C_0$  · polarization reduces  $E$

A polarized dielectric creates an internal field opposing the applied field

## Worked example – insert a dielectric with the battery removed

**A 100 pF capacitor is charged to 12 V, then filled with a  $\kappa = 3$  dielectric. Find the new  $\Delta V$  and  $U$ .**

- disconnected  $\Rightarrow Q$  is trapped:  
 $Q = C_0 \Delta V_0 = 1.2 \text{ nC}$
- $C = \kappa C_0 = 300 \text{ pF}$ , so  $\Delta V = Q/C = 4.0 \text{ V}$
- $U = \frac{Q^2}{2C}$  falls to a **third**:  $7.2 \rightarrow 2.4 \text{ nJ}$

Write down which quantity is held fixed first –  $Q$  if the battery is removed,  $\Delta V$  if it stays connected – then let  $C = \kappa C_0$  drive everything else. Get that wrong and every later line is wrong.

# What a dielectric is, and what it does

## dielectric

an **insulating** material: its charges cannot travel, but each molecule stretches or turns in a field

## the effect

the material **polarizes** and sets up its own opposing field, weakening the net field in the gap

## so

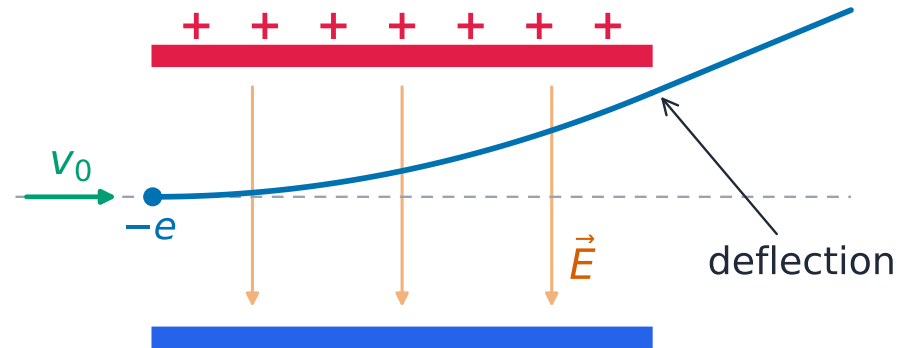
$C = \kappa C_0$ , where  $\kappa$  is the **dielectric constant** – the ratio of the material's permittivity to the **permittivity of free space**  $\epsilon_0$

## $\kappa$ is always $> 1$

a dielectric can only *raise* capacitance, never lower it

It also lets the plates sit closer without arcing, which raises  $C$  a second time through the smaller  $d$ .

# Capacitors, continued



$a_y = qE/m$  ·  $a_x = 0$  (same kinematics as a projectile under gravity)

between plates:  $a = qE/m$  constant · parabolic path

A charged particle between the plates follows a parabola, like a projectile

## Exercises 2.1-2.3

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**2.1** State what happens to a dielectric placed in an electric field. [1]

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**2.2** A capacitor  $C_0 = 2.0 \mu\text{F}$  has a dielectric of  $\kappa = 3.0$  inserted. Find the new capacitance. [2]

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**2.3** State what a dielectric does to the field between the plates at fixed charge. [1]

## Exercises 2.1-2.3

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**2.1** State what happens to a dielectric placed in an electric field. [1]

**2.1**

- it becomes polarized (its charges shift to partly oppose the field)

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**2.2** A capacitor  $C_0 = 2.0 \mu\text{F}$  has a dielectric of  $\kappa = 3.0$  inserted. Find the new capacitance. [2]

**2.2**

- $C = \kappa C_0 = 3.0 \times 2.0 = 6.0 \mu\text{F}$

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**2.3** State what a dielectric does to the field between the plates at fixed charge. [1]

**2.3**

- it reduces the field

## Exercises 3.1-3.2

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**3.1** Inserting a dielectric ( $\kappa > 1$ ) makes the capacitance

[1]

☐

**A** smaller

**B** larger

**C** zero

**D** unchanged

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**3.2** A dielectric is an

[1]

☐

**A** conductor

**B** insulator that polarizes

**C** source of charge

**D** magnet

## Exercises 3.1-3.2

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**3.1** Inserting a dielectric ( $\kappa > 1$ ) makes the capacitance

[1]

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A smaller

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C zero

D unchanged

**3.1 B**

- larger.

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**3.2** A dielectric is an

[1]

☐

A conductor

B insulator that polarizes

C source of charge

D magnet

**3.2 B**

- insulator that polarizes.

## Exercise 3.3 (a)

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**3.3** A  $4.0 \mu\text{F}$  capacitor is charged to  $50 \text{ V}$ , then **disconnected**; a dielectric of  $\kappa = 2.0$  is inserted.

(a) Find the new capacitance.

[1]

## Exercise 3.3 (a)

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**3.3** A  $4.0 \mu\text{F}$  capacitor is charged to  $50 \text{ V}$ , then **disconnected**; a dielectric of  $\kappa = 2.0$  is inserted.

(a) Find the new capacitance.

[1]

(a)

- $C = \kappa C_0 = 2.0 \times 4.0 = 8.0 \mu\text{F}$

## Exercise 3.3 (b)

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**3.3** A  $4.0 \mu\text{F}$  capacitor is charged to  $50 \text{ V}$ , then **disconnected**; a dielectric of  $\kappa = 2.0$  is inserted.

(b) State what happens to the voltage, and why.

[2]

## Exercise 3.3 (b)

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**3.3** A  $4.0 \mu\text{F}$  capacitor is charged to  $50 \text{ V}$ , then **disconnected**; a dielectric of  $\kappa = 2.0$  is inserted.

(b) State what happens to the voltage, and why. [2]

(b)

- the voltage halves to  $25 \text{ V}$  – the charge is fixed and  $V = Q/C$ , so doubling  $C$  halves  $V$