

Charge storage, energy and RC time constants

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet

Name: _____ Date: _____ Class: _____

These twenty problems start with $Q = CV$ and unit prefixes, then move through energy, combinations of capacitors and the exponential charge and discharge equations. They suit A Level, IB Physics and CBSE Class 12 students. The last five problems link several ideas and include energy loss, timer design and a medical device.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.7.4

Problem 1 Charge on a capacitor (easy)

A 2200 μF capacitor in a radio is charged to 6.0 V. Calculate the charge on one plate.

Problem 2 Prefix conversions (easy)

Chiamaka measures a capacitor that holds 2.4 μC at 12 V.

1. Calculate its capacitance in farads.
2. Express the answer in microfarads and in nanofarads.

Problem 3 Energy in a small capacitor (easy)

A 100 μF capacitor is charged to 25 V. Calculate the energy it stores.

Problem 4 Time constant (easy)

A circuit uses a 47 $\text{k}\Omega$ resistor and a 100 μF capacitor in series.

1. Calculate the time constant.
2. Estimate how long it takes the voltage to be practically zero during discharge (about 5τ).

Problem 5 Two capacitors (easy)

A 2.0 μF capacitor and a 3.0 μF capacitor are available.

1. Calculate the total capacitance when they are in parallel.
2. Calculate the total capacitance when they are in series.

Problem 6 Describing a discharge (easy)

1. Define capacitance.
2. Describe how the current and the voltage change as a capacitor discharges through a resistor.

- State the value of the voltage after one time constant as a fraction of the initial voltage.

Problem 7 Camera flash (medium)

A flash unit stores charge on a $150\ \mu\text{F}$ capacitor charged to $300\ \text{V}$. The flash lasts $1.0\ \text{ms}$.

- Calculate the charge stored.
- Calculate the energy stored.
- Calculate the average power during the flash, assuming all the energy is released.

Problem 8 Memory back-up (medium)

A $1000\ \mu\text{F}$ capacitor charged to $9.0\ \text{V}$ keeps a clock memory alive by supplying a constant $2.0\ \text{mA}$ for $1.5\ \text{s}$.

- Calculate the charge removed from the capacitor.
- Calculate the fall in voltage.
- Calculate the voltage across the capacitor at the end.

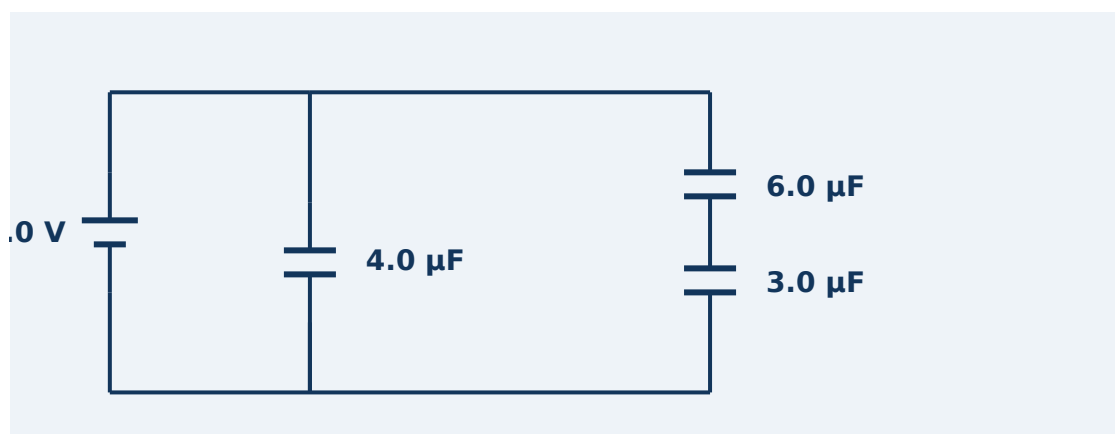
Problem 9 Three in series (medium)

Three capacitors of $6.0\ \mu\text{F}$, $3.0\ \mu\text{F}$ and $2.0\ \mu\text{F}$ are connected in series across a $12\ \text{V}$ supply.

- Calculate the total capacitance.
- Calculate the charge on each capacitor.
- Calculate the voltage across each capacitor.

Problem 10 Network of capacitors (medium)

Aarav in Pune builds the network shown, supplied by a $9.0\ \text{V}$ battery.



Circuit for the combination problem.

- Calculate the capacitance of the series pair.
- Calculate the total capacitance of the network.
- Calculate the total charge supplied and the energy stored.

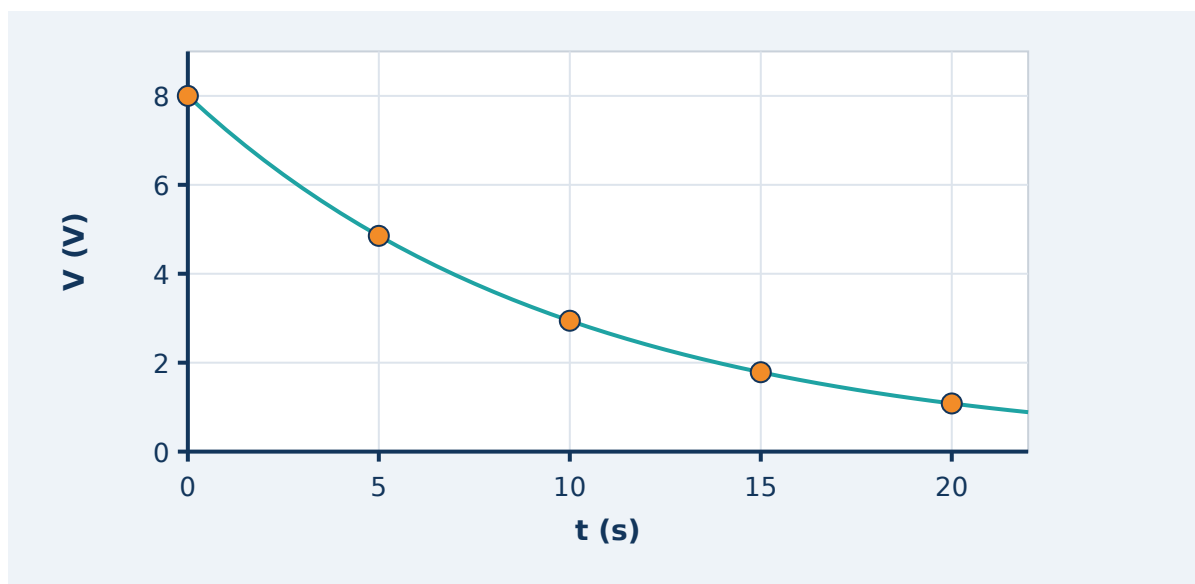
Problem 11 Discharge calculation (medium)

A $470\ \mu\text{F}$ capacitor charged to $12\ \text{V}$ discharges through a $22\ \text{k}\Omega$ resistor.

1. Calculate the time constant.
2. Calculate the voltage after $15\ \text{s}$.
3. Calculate the initial current.

Problem 12 Finding τ from a graph (medium)

The graph shows a capacitor discharging through a $10\ \text{k}\Omega$ resistor.



Discharge of a capacitor: $V = 8.0\ \text{V}$ at $t = 0$, $4.85\ \text{V}$ at $5\ \text{s}$, $2.94\ \text{V}$ at $10\ \text{s}$, $1.78\ \text{V}$ at $15\ \text{s}$ and $1.08\ \text{V}$ at $20\ \text{s}$.

1. State the initial voltage and calculate 37 % of it.
2. Use the graph to find the time constant.
3. Calculate the capacitance.

Problem 13 Charging a capacitor (medium)

A $2200\ \mu\text{F}$ capacitor, initially uncharged, charges from a $9.0\ \text{V}$ supply through a $4.7\ \text{k}\Omega$ resistor.

1. Calculate the time constant.
2. Calculate the voltage across the capacitor after $10\ \text{s}$.
3. Calculate the time taken to reach $6.0\ \text{V}$.

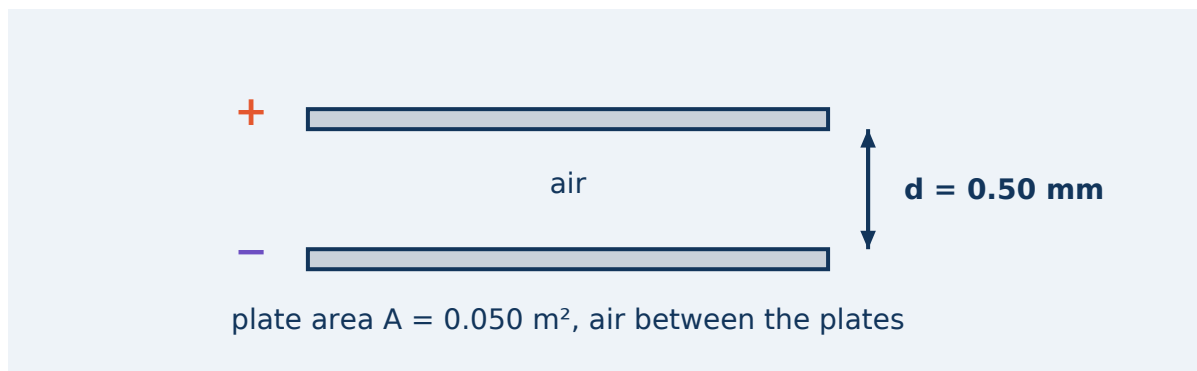
Problem 14 Spot the error (medium)

A student has an RC circuit with $R = 2.2\ \text{k}\Omega$ and $C = 470\ \mu\text{F}$. She writes: " $\tau = 2.2 \times 470 = 1034\ \text{s}$, so the capacitor is completely discharged after one time constant."

1. Identify the two mistakes.
2. Calculate the correct time constant.
3. State the voltage after one time constant when $V_0 = 6.0\ \text{V}$.

Problem 15 Parallel-plate capacitor (medium)

A capacitor is made from two plates with an air gap, using $\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$.



Parallel-plate capacitor with an air gap (the diagram is not to scale).

1. Calculate the capacitance from $C = \epsilon_0 A / d$.
2. Calculate the charge stored at 100 V.
3. State the effect on C of halving the separation.

Problem 16 Sharing charge (hard)

Mei in Singapore charges a $4.0 \mu\text{F}$ capacitor to 12 V, disconnects it from the supply, and then connects it across an uncharged $2.0 \mu\text{F}$ capacitor.

1. Calculate the initial charge.
2. Calculate the final voltage across the pair.
3. Calculate the energy before and after, and explain the difference.

Problem 17 Energy and time constant (hard)

A $1000 \mu\text{F}$ capacitor charged to 10 V discharges through a $1.0 \text{ k}\Omega$ resistor.

1. Calculate the initial energy stored.
2. Show that the energy stored falls with time as $E = E_0 e^{-2t/\tau}$.
3. Calculate the time for the stored energy to fall to 25 % of its initial value, and the voltage at that time.

Problem 18 Delay timer design (hard)

Kofi in Accra wants a lamp to switch on 30 s after pressing a button. The lamp turns on when a $470 \mu\text{F}$ capacitor, charging from a 9.0 V supply through a resistor R, reaches 6.0 V.

1. Show that the delay is $t = RC \ln 3$.
2. Calculate the resistance needed for a 30 s delay.
3. The nearest standard value is $56 \text{ k}\Omega$. Calculate the actual delay.

Problem 19 Linearising the decay (hard)

Bilal in Lahore records the voltage on a capacitor discharging through a $40 \text{ k}\Omega$ resistor:

t (s)	0	10	20	30	40
V (V)	10.00	6.07	3.68	2.23	1.35

1. Calculate $\ln V$ for each reading.
2. Explain why a graph of $\ln V$ against t is a straight line and find its gradient.
3. Determine the time constant and the capacitance.

Problem 20 Defibrillator pulse (hard)

A defibrillator charges a $32 \mu\text{F}$ capacitor to 5.0 kV . During a shock it discharges through the patient, whose body has a resistance of 50Ω .

1. Calculate the energy stored.
2. Calculate the initial current and the time constant.
3. Calculate the energy delivered in the first 2.0 ms .