9702 C19 Capacitance

Capacitors and capacitance

Capacitors are electrical devices used to stored energy in circuits (commonly for a backup release of energy if the power fails)

Capacitors can be in the form of:

1.An isolated spherical conductor

2.Parallel plates

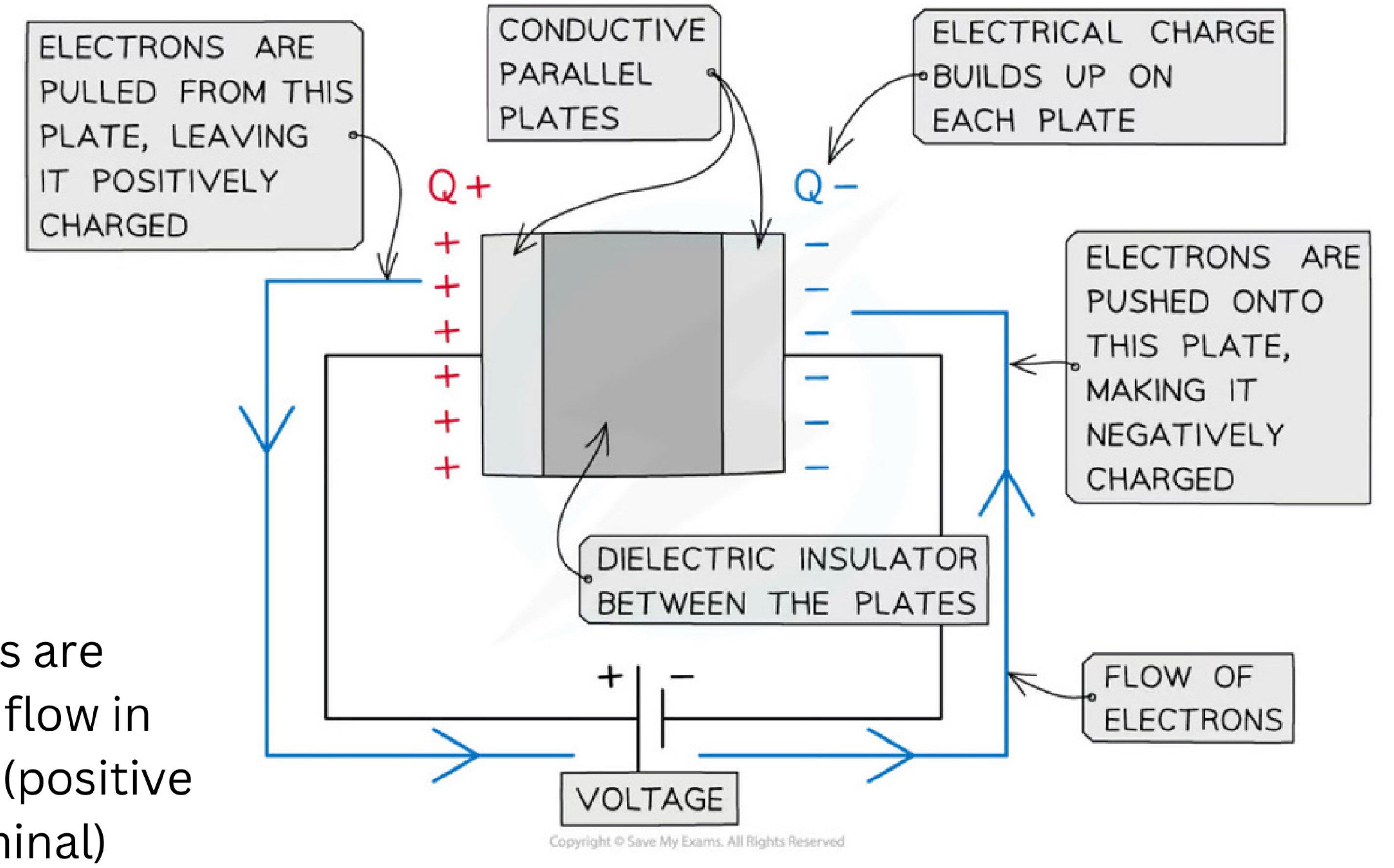
Capacitance = quantity of the **charge stored per unit potential difference**

$$C = \frac{Q}{V}$$

C=capacitance (F=farad)
Q=charge (C)
V=potential difference(V)

(C is often written in microfard and nanofarad)

When capacitors are charged, electron flow in convention current (positive to negative terminal)



A parallel plate capacitor is made up of two conductive plates with opposite charges building up on each plate

Q is NOT the charge of the capacitor itself, it is the charged stored ON the plates or spherical conductors

Capacitance of a Spherical Conductor

- The potential V is defined by the potential of an isolated point charge (since the charge on the surface of a spherical conductor can be considered as a point charge at its centre):

$$V = \frac{Q}{4\pi\varepsilon_0 r} = \frac{kQ}{r} \qquad \left(k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ mF^{-1} \right)$$

- Substituting this into the capacitance equation means the capacitance C of a sphere is given by the expression:

$$C = 4\pi\varepsilon_0 r = \frac{r}{k}$$

Derivation of C=Q/V in series and parallel

The circuit symbol for a parallel plate capacitor is two parallel lines

series

① $V = V_1 + V_2 + \ldots$

② $V_1 = \frac{Q}{C_1}$ $V_2 = \frac{Q}{C_2}$

③ $V = \frac{Q}{C_{total}}$

$\frac{Q}{C_{total}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \ldots$

④ $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

parallel

① $Q = Q_1 + Q_2 + \ldots$

② $Q_1 = C_1 V$ $Q_2 = C_2 V$

③ $Q = C_{total} V$

$C_{total} V = C_1 V + C_2 V + \ldots$
$= (C_1 + C_2 + \ldots) V$

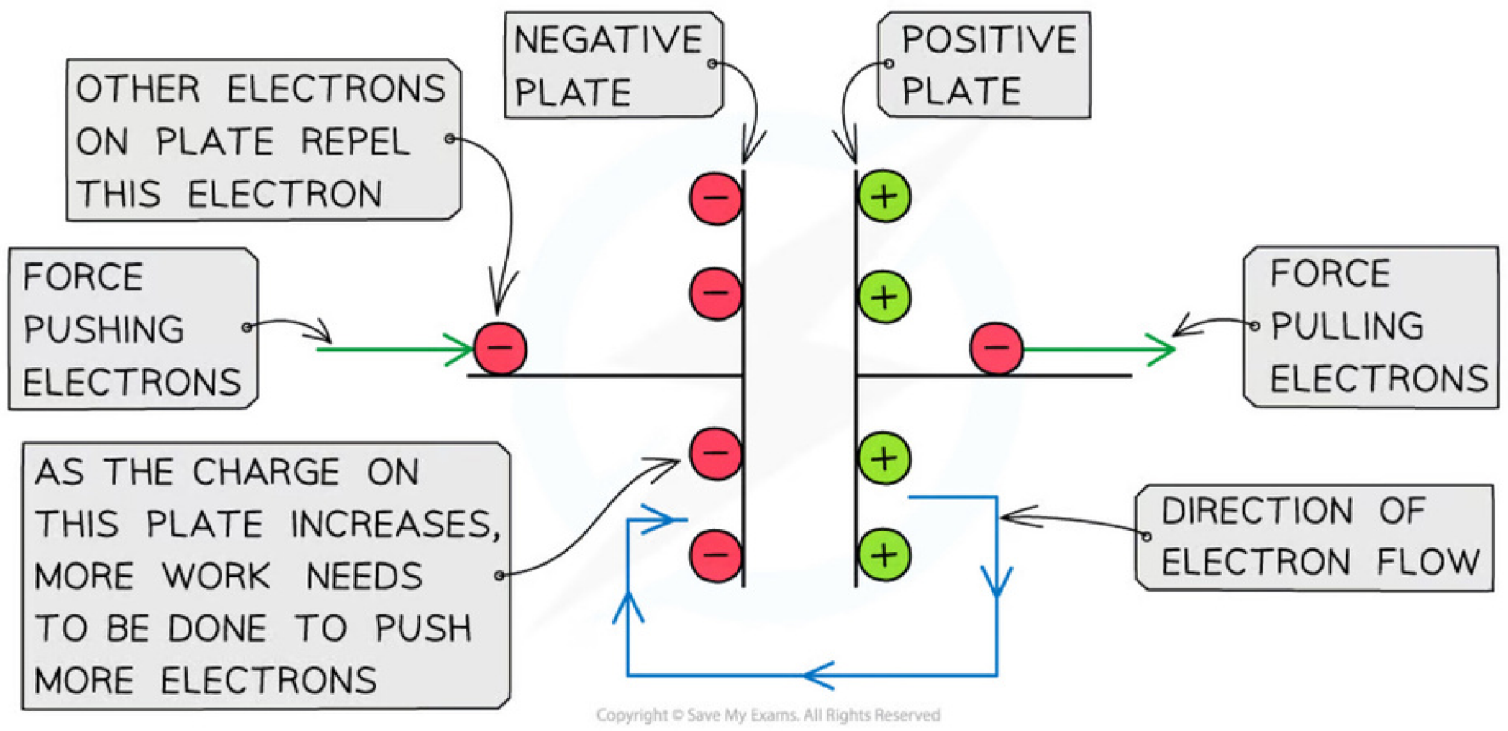
④ $C_{total} = C_1 + C_2 + \ldots$

Area under a Potential-Charge Graph

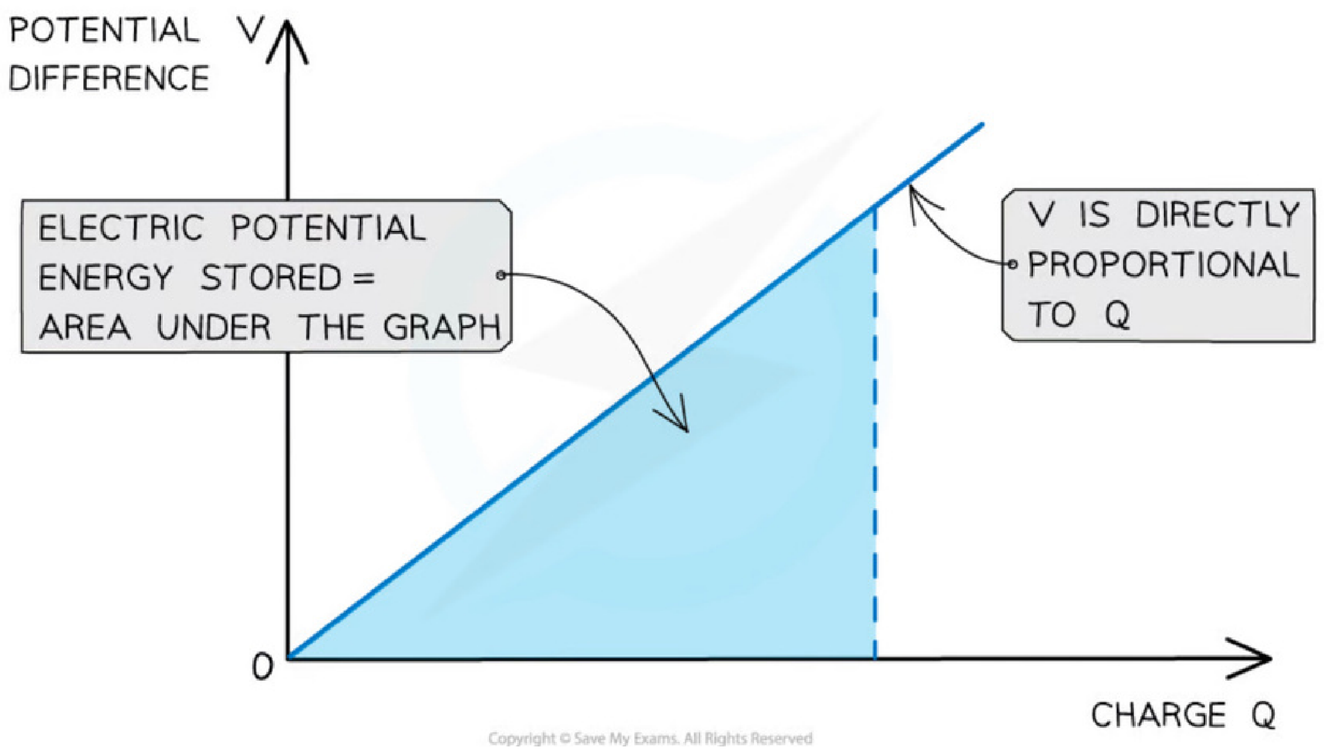
When charging a capacitor, the power supply pushes electrons from + to - plate
-->work is done on the eletrons, which increase electric potential energy

Adding more e- to the negative plate at first is easy because there is little repulsion, but as the e- builds up, more work is required to overcome higher repulsion

-->The greater amount of work must be done to increase the charge on the negative plate
(i.e. **the potential difference V across the capacitor increases as the amount of charge Q increases**)



electric potential energy $= \text{Area} = \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$



Capacitor Discharging Graph

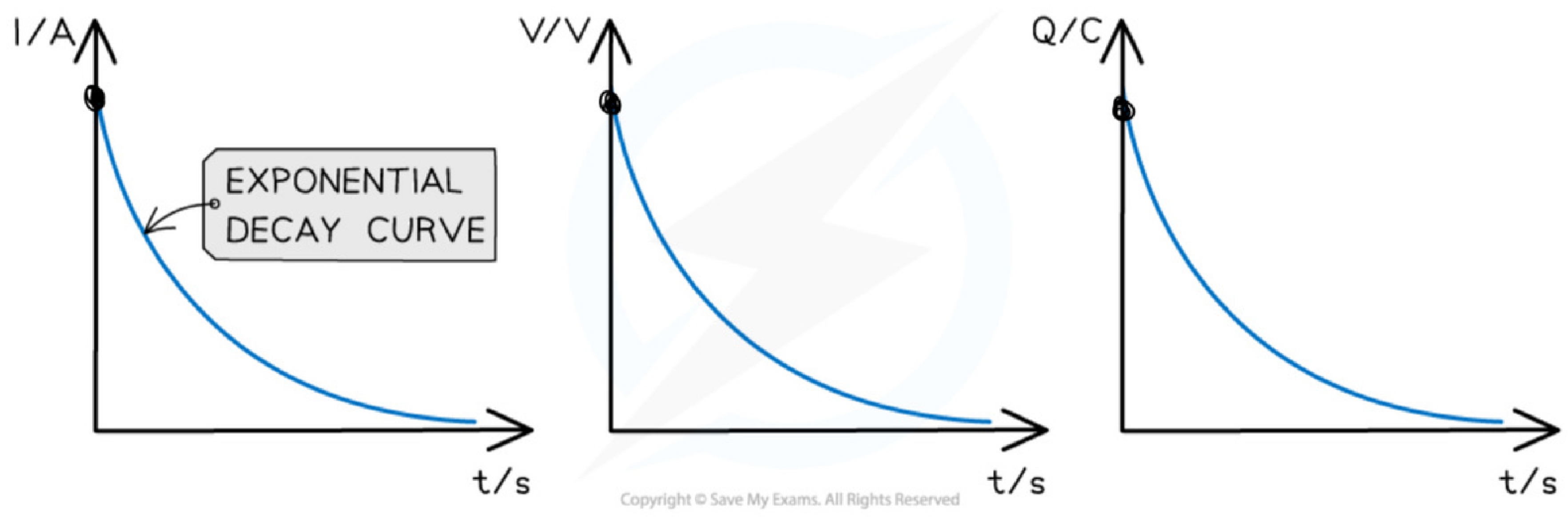
Capacitors are discharged through a resistor

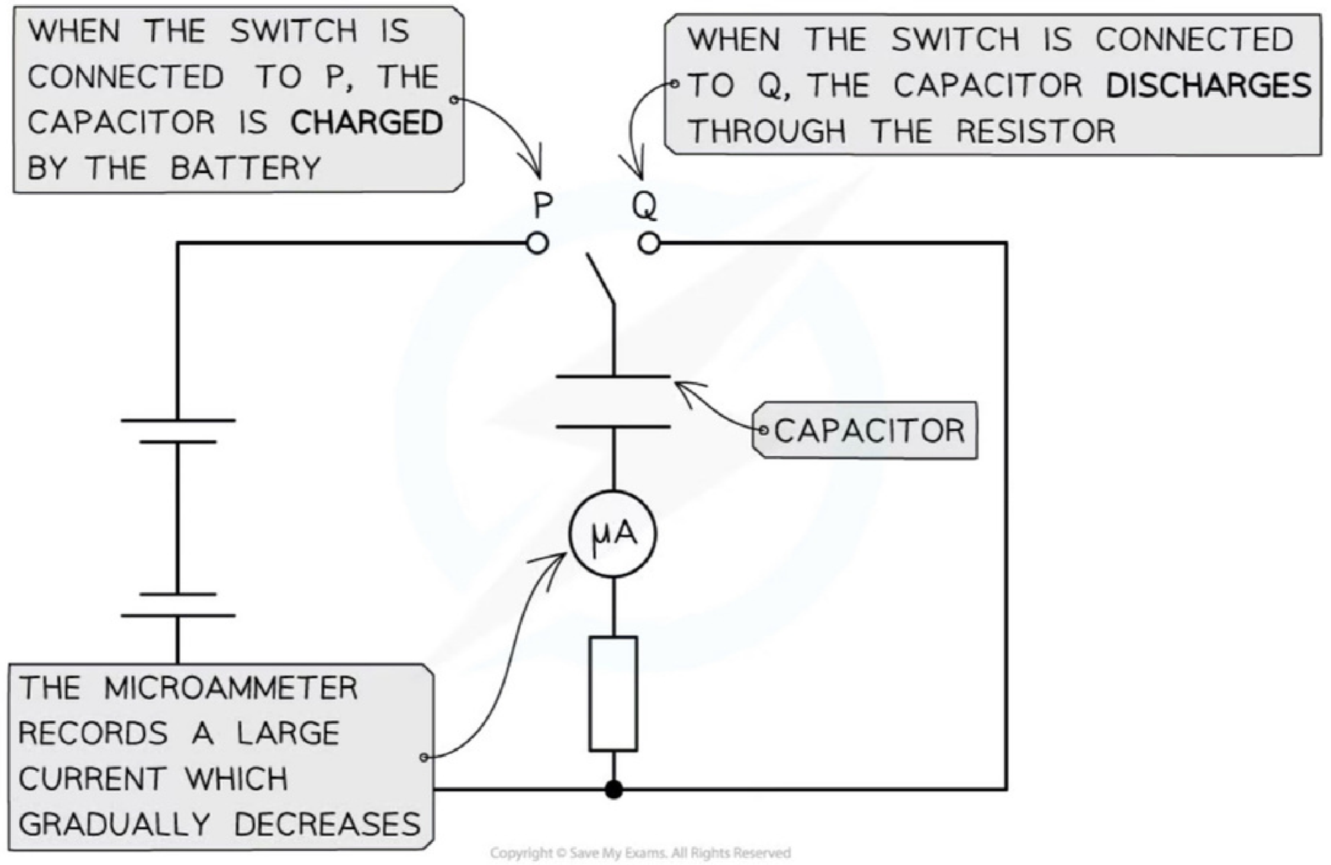
-->the electrons now flow back from negative to positive plate until it reaches equilibrium (when there are equal number of e- on each plate)

at the start of discharge, the current is large and current, p.d. and charge all decrease <u>exponentially</u> to zero

(this means rate at which the current, p.d. or charge decreases is proportional tothe amount of current, p.d. or charge it has left)

high resistance = current decrease = charge flow slowly = capacitor take longer to discharge





Capacitor Discharge Equations

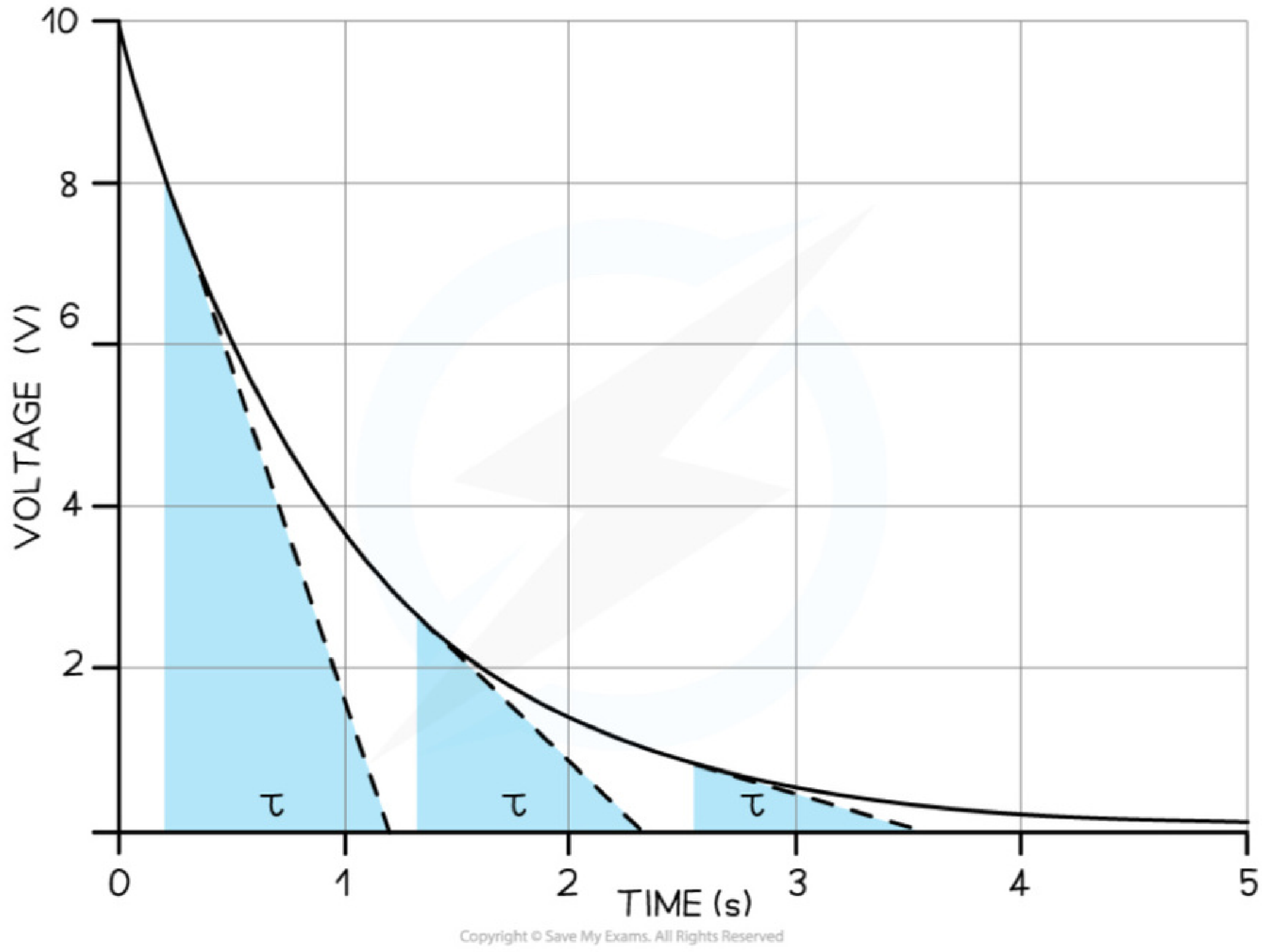
Time constant of a capacitor discharging is represented by 'tau" (**τ**)

time constant = time taken for the charge of a capacitor to decrease to 0.37(1/e) of its original value

$$\tau = RC$$

Where:

- τ = time constant (s)
- R = resistance of the resistor (Ω)
- C = capacitance of the capacitor (F)



The graph of voltage-time for a discharging capacitor showing the positions of the first three time constants

$$I = I_0 e^{-\frac{t}{RC}}$$

$$V = V_0 e^{-\frac{t}{RC}}$$

$$Q = Q_0 e^{-\frac{t}{RC}}$$

Where:

- I = current (A)
- I_0 = initial current before discharge (A)
- e = the exponential function
- t = time (s)
- RC = resistance (Ω) × capacitance (F) = the time constant τ (s)