Physics. You work it out.

Further Electricity

A-level overview

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Alternating Current

Direct and alternating current

Batteries and cells give direct current

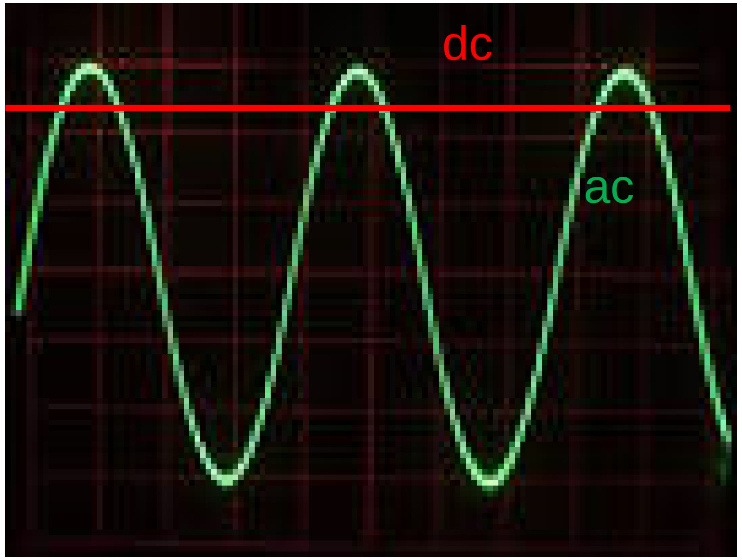
The voltage is constant

The mains (made by coils of wire rotating in magnetic fields) is alternating current.

The voltage varies in time like the positionof an oscillator

$$V = V_{pk}\cos(\omega t)$$

The mean voltage is zero



Power in a.c.

If

$$V = V_{pk}\cos(\omega t)$$

then the current

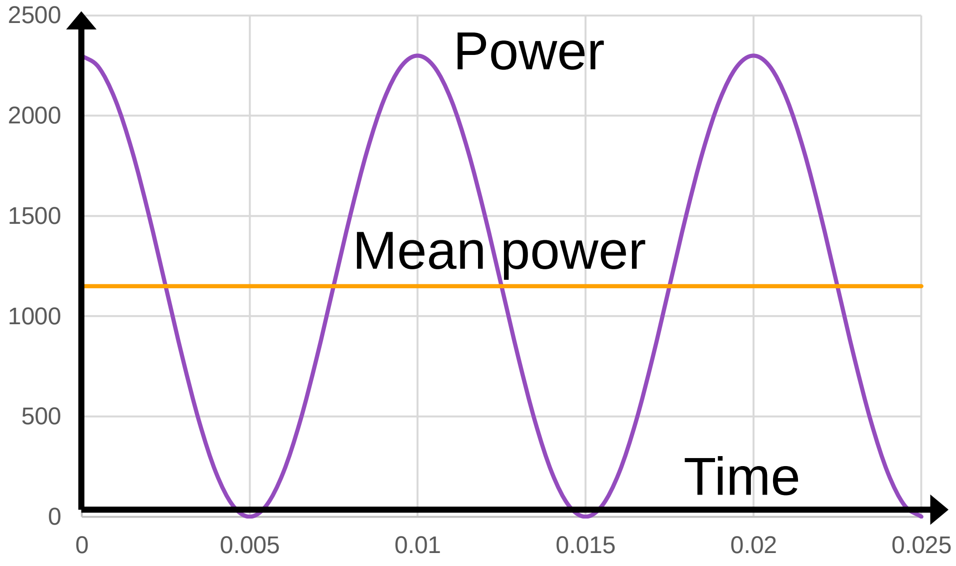
$$I = \frac{V}{R} = \frac{V_{pk}}{R}\cos(\omega t)$$

and the power

$$P = VI = \frac{V_{pk}^2}{R}\cos^2(\omega t)$$

so average power

$$P_{av} = \frac{V_{pk}^2}{2R} = \frac{1}{R}\left(\frac{V_{pk}}{\sqrt{2}}\right)^2$$



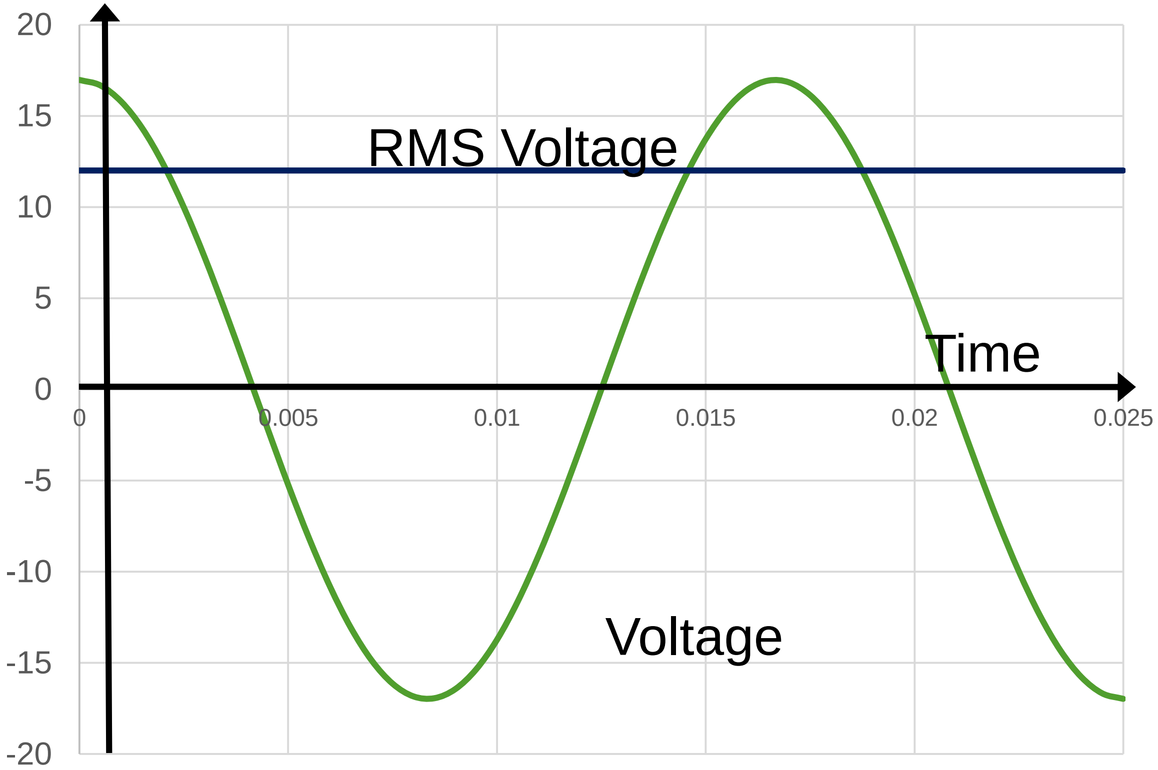
which is the same as the powered delivered by a d.c. voltage $V_{rms} = \frac{V_{pk}}{\sqrt{2}}$

RMS

For UK mains,

V_{rms}=230V so V_{pk} =325V
f= 50Hz

If you use RMS values for current and voltage and mean value for power, d.c. equations $P=IV$, $P=I^2R$ etc still work.



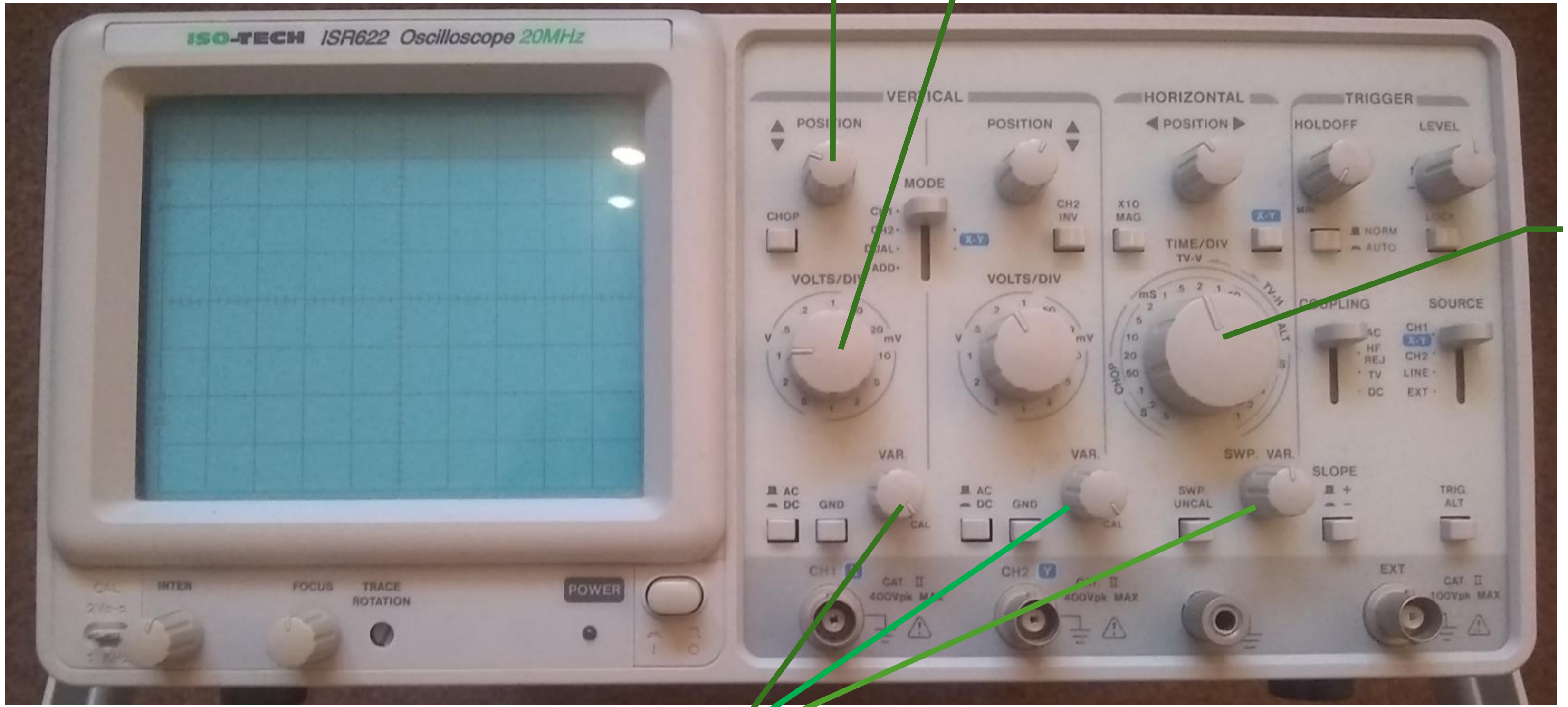
RMS means ‘root mean square’

V_{rms} = square root of the average of V^2

Oscilloscopes

y-pos
Moves trace up and down

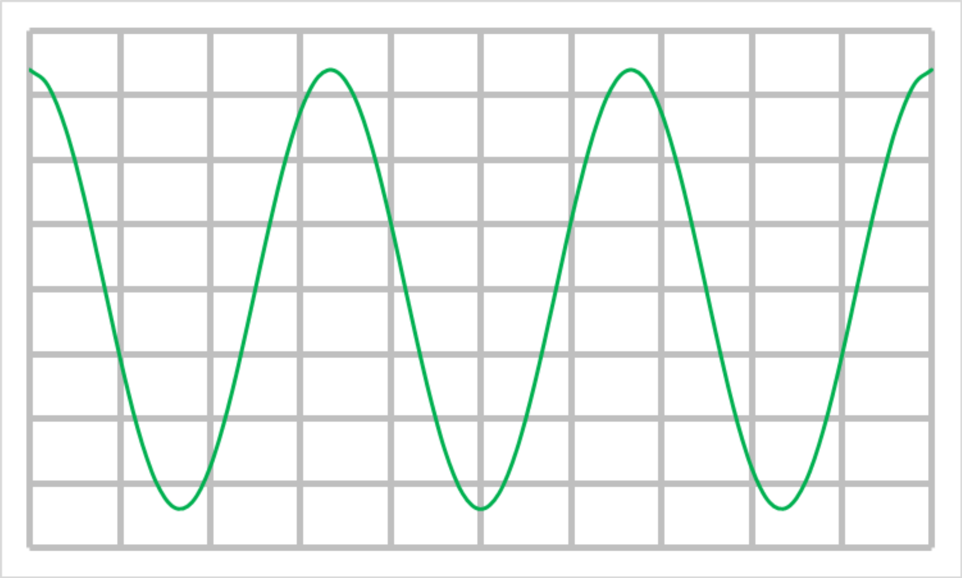
Sensitivity
V/div on vertical



Time base
s/div on horizontal

Variable sensitivity
set to CAL

Alternating current practice



An oscilloscope is set to a y-gain of 2V/div and a time base of 20ms/div

From this trace, work out the frequency, the RMS voltage and the power if this were connected to a 12Ω resistor.

Capacitors

Introducing capacitors

Positively charged plate +Q

Dielectric = insulator

Negatively charged plate -Q

In a capacitor charge is separated

Charge 'stored' is proportional to voltage

$$Q = CV$$

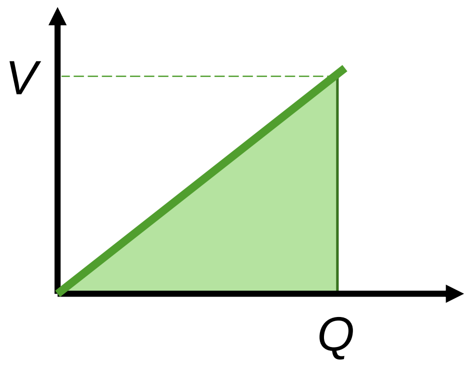
C is capacitance, measured in farads F. 1F = 1C/V

Often, capacitors are measured in $\mu F = 10^{-6} F$, $nF = 10^{-9} F$, or $pF = 10^{-12} F$

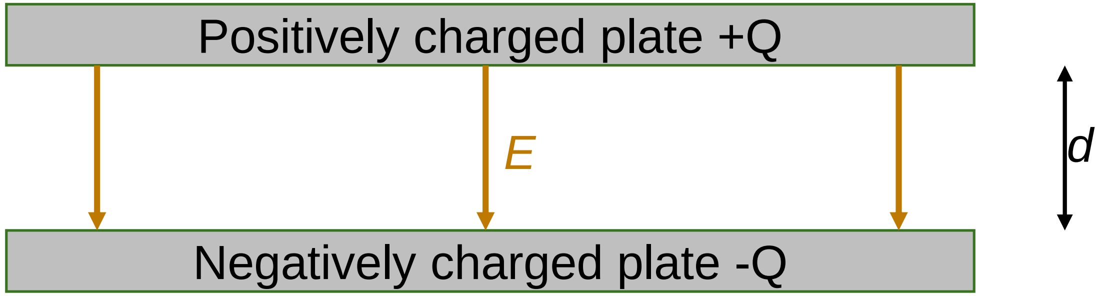
Always connect capacitor with correct polarity

Energy stored = area under V vs q graph

$$U = \frac{1}{2}QV = \frac{1}{2}CV^2$$



Capacitance and field



Field proportional to charge $\epsilon E A = Q$

Electric field related to voltage $E = \frac{V}{d}$

$$Q = \epsilon E A = \epsilon \frac{VA}{d} \qquad C = \frac{Q}{V} = \frac{\epsilon A}{d}$$

Capacitor practice

1. Calculate the charge stored on a 20nC capacitor connected to a 6.5V battery.

2. Calculate the energy stored in the capacitor in q1.

3. Calculate the capacitance needed to store 2.5J at 12V.

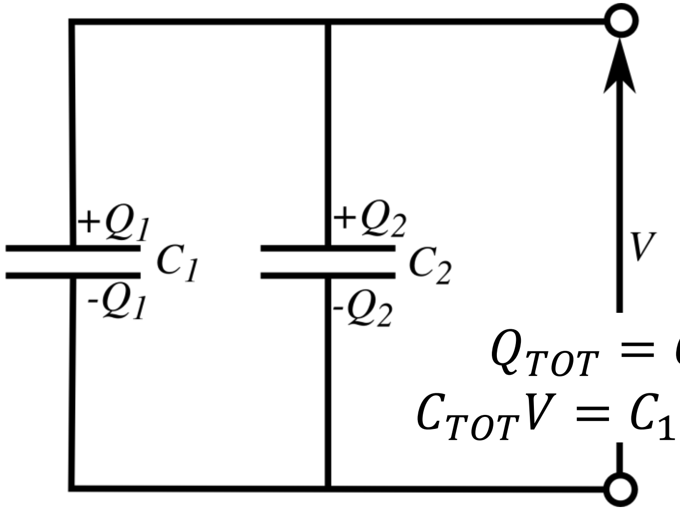
Capacitor networks

- **Capacitors in parallel: like resistors in series**

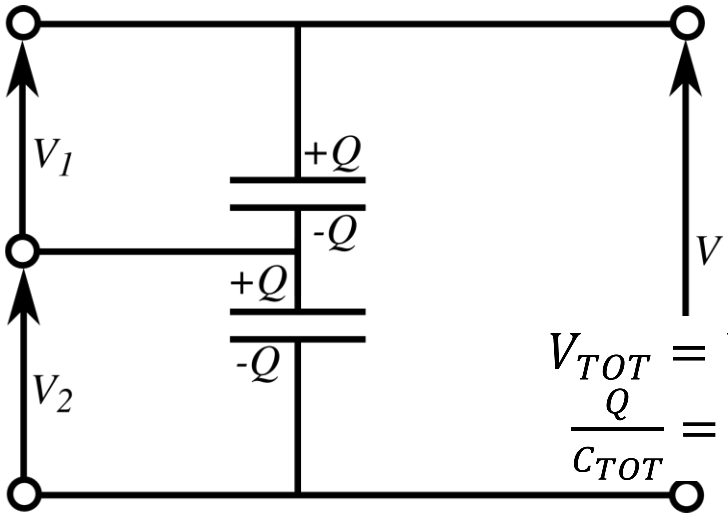
$$C_{TOT} = C_1 + C_2$$

- **Capacitors in series: like resistors in parallel**

$$C_{TOT} = \left(C_1{}^{-1} + C_2{}^{-1}\right)^{-1}$$



$$Q_{TOT} = Q_1 + Q_2$$
$$C_{TOT}V = C_1V + C_2V$$



$$V_{TOT} = V_1 + V_2$$
$$\frac{Q}{C_{TOT}} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

Example

- A 1000μF capacitor is charged using a 10V battery.
- It is then connected to an uncharged 500μF capacitor.
- What is the new voltage?

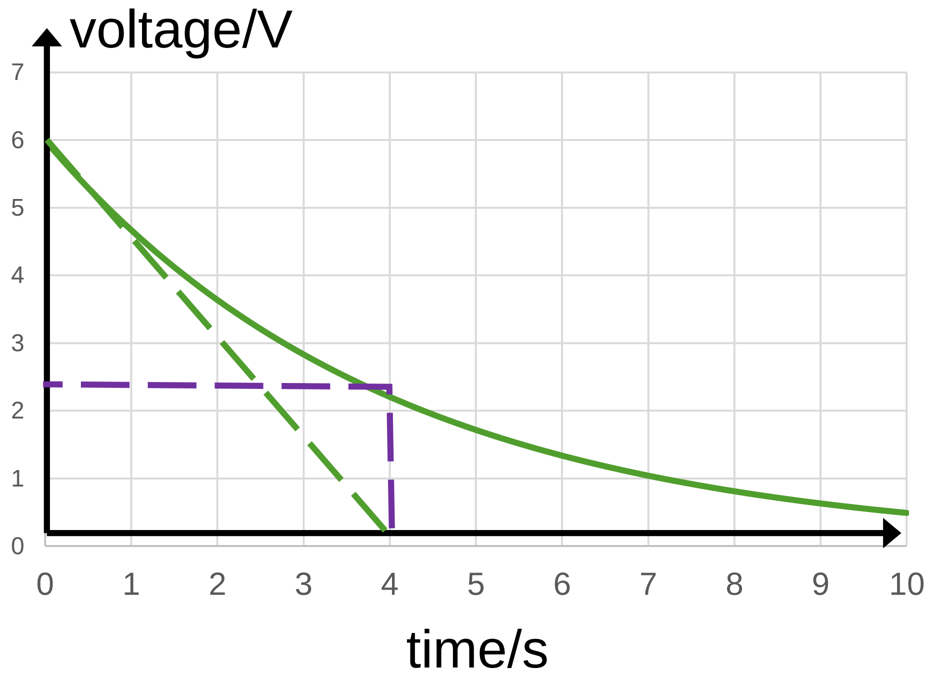
Capacitor network practice

1. Calculate the capacitance of 4nF, 10nF and 15nF capacitors connected in parallel.

2. Calculate the capacitance of a 24μF capacitor connected in series with a 16μF capacitor.

3. A 220μF capacitor is connected to a 12V battery, it is then connected in parallel with an uncharged 630μF capacitor. What is the voltage now?

Time constant



After one time constant, voltage has fallen to $\frac{V_0}{e} \approx 0.37V_0$

- **Initial discharge current**

$$I_0 = \frac{V_0}{R} = \frac{Q_0}{RC}$$

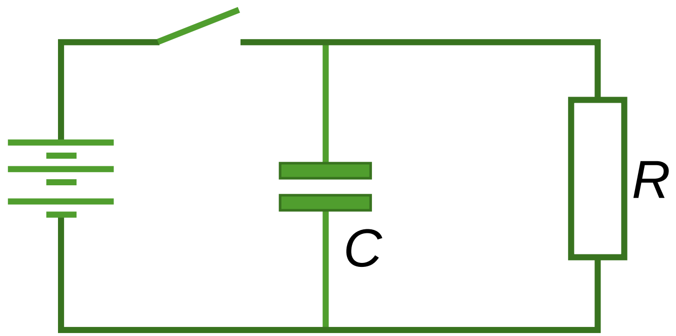
- **If this current were constant, the capacitor would discharge in time constant**

$$t = \frac{Q_0}{I_0} = RC$$

- **During discharge, Q drops so $V = \frac{Q}{C}$ drops, so $I = \frac{V}{R} = \frac{Q}{RC}$ drops and rate of discharge falls**

Capacitor discharge

$$I = \frac{V}{R} = \frac{Q}{RC}$$



If I=0.05A, then Q gets smaller by 0.05C each second, thus

$$I = -\frac{dQ}{dt} = \frac{Q}{RC}$$

Solution

$$I = I_0 e^{-\frac{t}{RC}}, \qquad V = V_0 e^{-\frac{t}{RC}}, \qquad Q = Q_0 e^{-\frac{t}{RC}}$$

Solving for time

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

taking natural logarithms (ln 1 = 0, ln e = 1, ln e^2 = 2, ln e^3 = 3)

$$\ln\frac{V}{V_0} = -\frac{t}{RC}$$

If voltage has halved, $V_0 = 2V$, and

$$\ln\tfrac{1}{2} = -\frac{t}{RC} \qquad -0.693 = -\frac{t}{RC} \qquad t = 0.693\,RC$$

Capacitor discharge practice

1. Calculate the time constant of a circuit containing a 2200μF capacitor and a 200kΩ resistor.

2. What is the initial discharge current if the capacitor in q1 starts with a voltage of 12V?

3. What will the discharge current be 880s after the start?

4. When will the voltage have dropped to 10V?

Links

A Level Topic Revision

https://isaacphysics.org/pages/a_level_topic_index#a_level_revision

Consolidation Programme

https://isaacphysics.org/pages/summer_programmes_2021