

# Alternating currents

A-Level Physics

## Alternating current basics



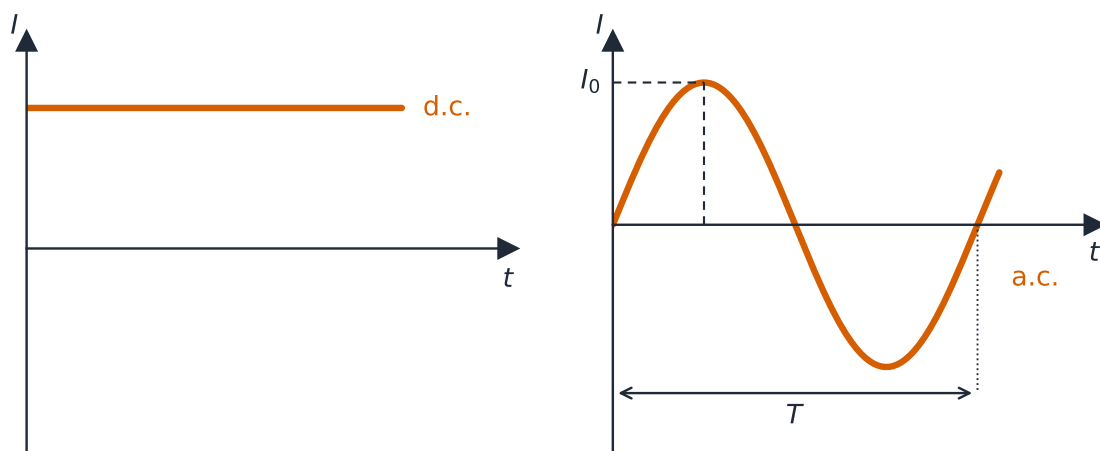
*A substation's transformers step alternating voltage up or down.*

Image: Bob Harvey, CC BY-SA 2.0 (commons.wikimedia.org)

An **alternating current** 交流电 (a.c.) keeps reversing direction. Mains supply is sinusoidal a.c.:  $I$  or  $V$  follows a sine wave in time:

$$I = I_0 \sin(\omega t), \quad V = V_0 \sin(\omega t).$$

(For a purely resistive load the **voltage** 电压 and **current** 电流 are in phase, which is the case in this syllabus.)



*A steady direct current compared with a sinusoidal alternating current of peak  $I_0$  and period  $T$*

## Key terms

- **period** 周期  $T$  —the time for one full cycle. Unit: s.
- **frequency** 频率  $f$  —cycles per second;  $f = 1/T$ . Mains is often 50 Hz or 60 Hz.
- **angular frequency** 角频率  $\omega = 2\pi f = 2\pi/T$ .
- **peak value** 峰值  $I_0$  or  $V_0$  —the largest value in a cycle (also called the amplitude).
- **peak-to-peak value** 峰峰值  $2I_0$  —from  $+I_0$  to  $-I_0$ . Useful when reading an oscilloscope.

## Reading a CRO trace

Same as for any wave (Topic 7), using a **cathode-ray oscilloscope** 示波器:

- horizontal divisions  $\times$  **time-base** 时基  $\rightarrow$  period  $T$ , so  $f = 1/T$ .
- vertical divisions  $\times$   $y$ -gain  $\rightarrow$  peak voltage  $V_0$  (measure centre to peak, or peak-to-peak then halve).

## Power delivered to a resistor

For a resistive load  $R$ , the instant **power** 功率 is  $P(t) = I(t)^2 R$ . With  $I = I_0 \sin(\omega t)$ :

$$P(t) = I_0^2 R \sin^2(\omega t).$$

This is always positive, with peak  $I_0^2 R$  and minimum zero, oscillating at twice the frequency of  $I$ . The mean of  $\sin^2(\omega t)$  over a cycle is  $\frac{1}{2}$ , so the **average power** is

$$\langle P \rangle = \frac{1}{2} I_0^2 R = \frac{1}{2} P_{\text{peak}}.$$

Average a.c. power in a resistor is **half the peak power**.

## Root-mean-square (r.m.s.) values

The r.m.s. current  $I_{\text{r.m.s.}}$  is the **steady direct current** that would give the same average power in the same **resistance** 电阻  $R$ . From  $\langle P \rangle = I_{\text{r.m.s.}}^2 R = \frac{1}{2} I_0^2 R$ :

$$I_{\text{r.m.s.}} = \frac{I_0}{\sqrt{2}}, \quad V_{\text{r.m.s.}} = \frac{V_0}{\sqrt{2}}.$$

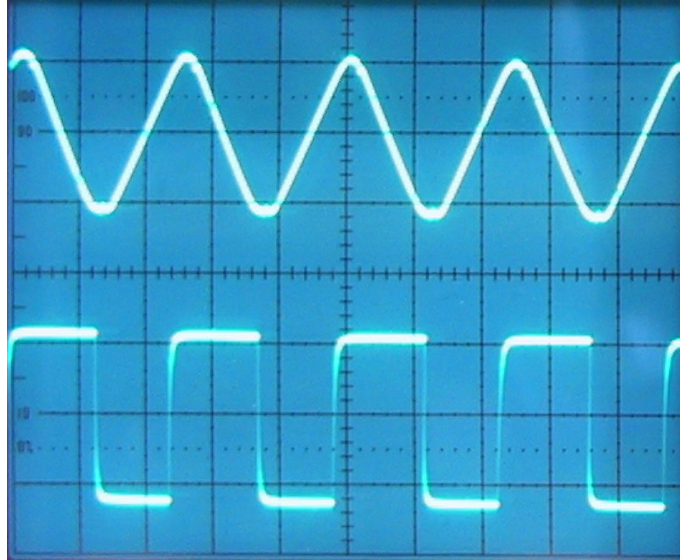
The  $\sqrt{2}$  comes from the name **root-mean-square** 均方根:  $I_{\text{r.m.s.}} = \sqrt{\langle I^2 \rangle}$  and  $\langle \sin^2 \rangle = \frac{1}{2}$ . (Only the sinusoidal case is needed.)

## Why r.m.s. matters

Quoted a.c. values are r.m.s. values. "230 V mains" means  $V_{\text{r.m.s.}} = 230$  V, with peak  $V_0 = 230\sqrt{2} \approx 325$  V. Components must be rated for the peak, not the r.m.s. Average power then takes the d.c. form:

$$\langle P \rangle = I_{\text{r.m.s.}}^2 R = V_{\text{r.m.s.}}^2 / R = V_{\text{r.m.s.}} I_{\text{r.m.s.}}$$

## Rectification



*An oscilloscope shows how a voltage varies with time.*

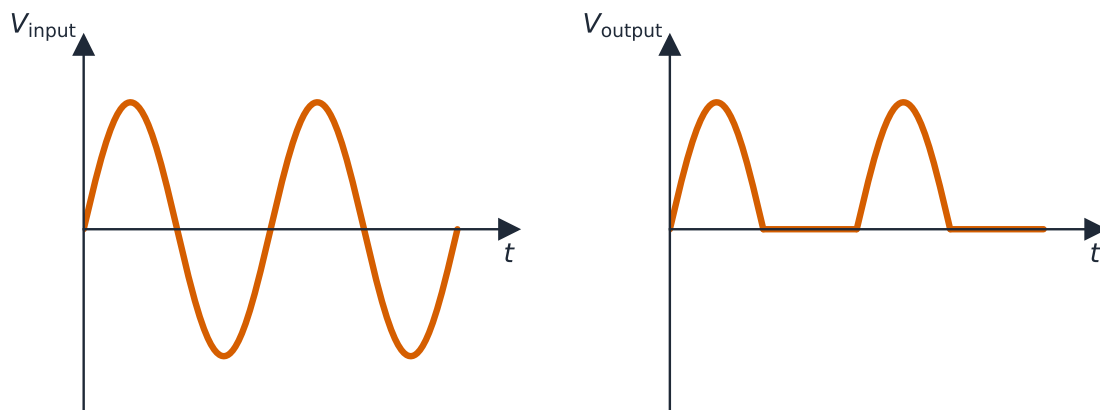
Image: User:Xato, CC0 (commons.wikimedia.org)

**Rectification** 整流 turns an alternating voltage into a one-direction (d.c.-like) voltage, using **diodes** 二极管 (which conduct in only one direction).

### Half-wave rectification

A **single diode** in series with the load passes only the positive half of each cycle; in the negative half the diode is **reverse-biased** 反向偏置 and no current flows. This is **half-wave rectification** 半波整流.

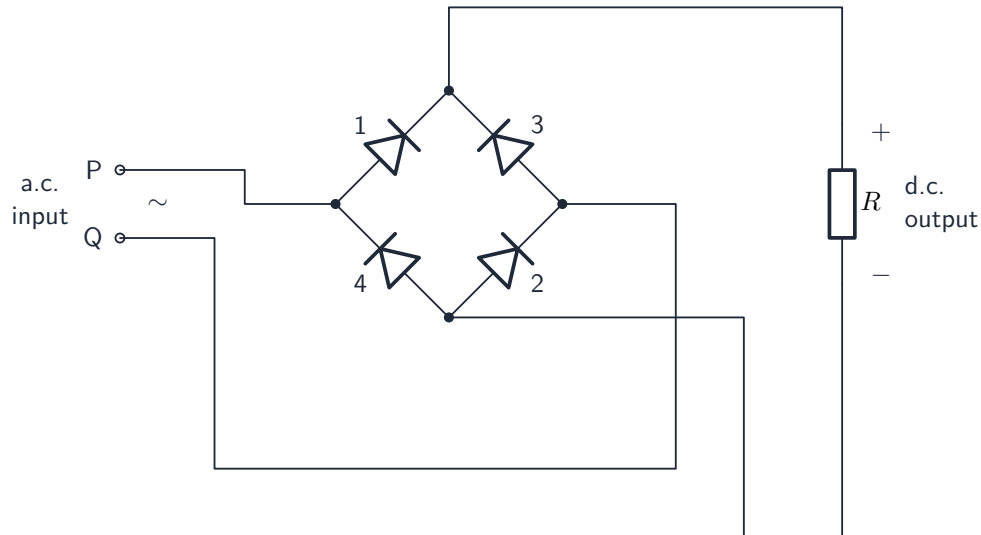
Output: positive half-waves with flat zero gaps. The mean output is  $V_0/\pi \approx 0.32V_0$ .  
Drawback: half the input is wasted and the output is very uneven.



*In half-wave rectification a single diode passes only the positive half-cycles*

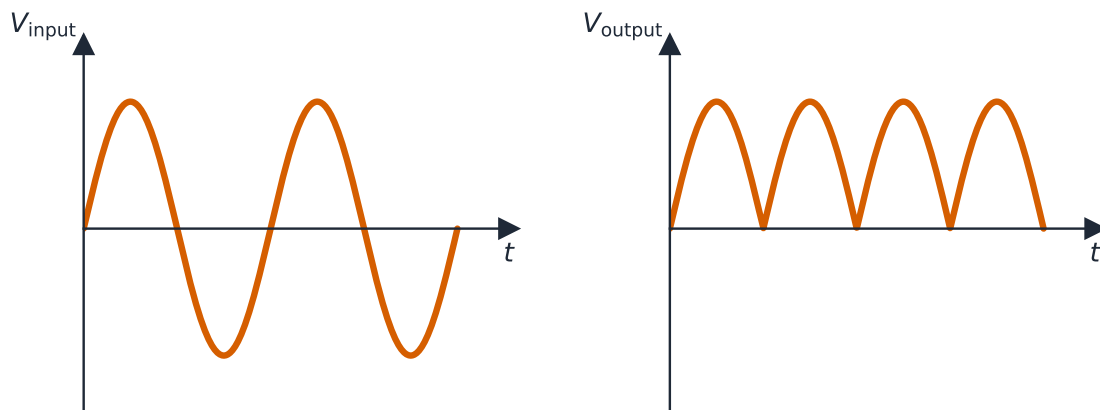
## Full-wave rectification (bridge rectifier)

A **bridge rectifier** 桥式整流器 uses **four diodes** arranged so the current through the load always flows the same way, whichever a.c. terminal is positive — **full-wave rectification** 全波整流. On each half-cycle a different pair of diodes conducts, but the load always sees the same direction.



*A four-diode bridge sends the load current the same way whichever a.c. terminal is positive*

Output: a continuous run of positive half-waves (no gaps), at **twice** the input frequency. The mean output is  $2V_0/\pi \approx 0.64V_0$  —double the half-wave value. It uses all the input and is smoother and easier to filter.



*In full-wave rectification every half-cycle is used, giving a continuous run of positive humps*

## Drawing the diagrams

- half-wave: a.c. source —single diode —load  $R$ , in series.
- full-wave bridge: four diodes as the arms of a "diamond"; the a.c. input goes to one pair of opposite corners, the load  $R$  across the other pair. The diode directions make the load terminals keep the same polarity for either input polarity.

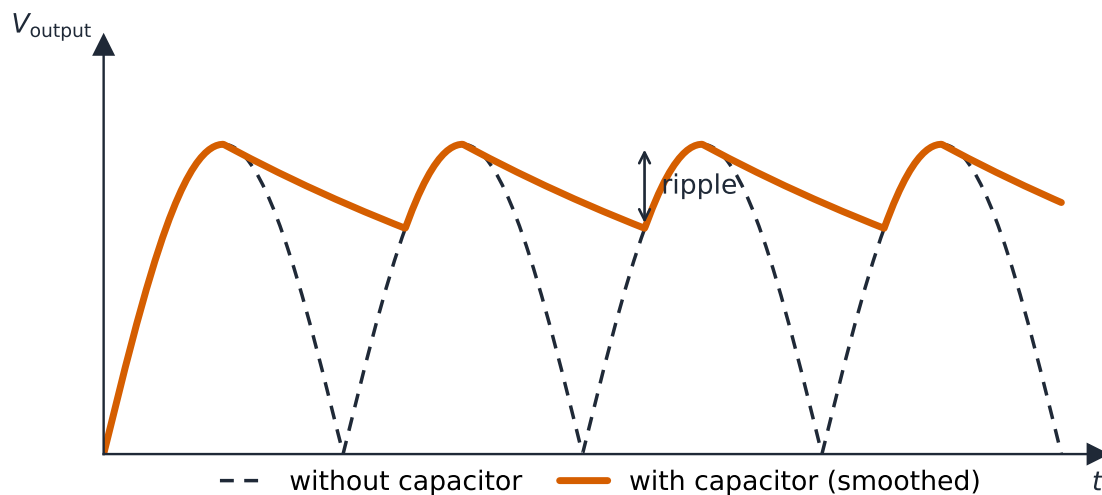
## Smoothing with a capacitor

A rectifier's output is still bumpy. To smooth it, put a **capacitor** 电容器  $C$  in parallel with the load  $R$ .

### How it works

- on the **rising part** of each pulse, the capacitor charges up to near the peak.
- on the **falling part** (and any gap), the diodes are reverse-biased, so the capacitor **discharges through the load**, keeping current flowing. The voltage falls with **time constant** 时间常数  $RC$  (Topic 19).
- at the next peak, the capacitor charges again, and the cycle repeats.

The output now sits near the peak with small dips. The size of the dips is the **ripple** 纹波 (this whole step is called **smoothing** 平滑).



*A capacitor across the load smooths the rectified output, leaving only a small ripple*

### What reduces the ripple

- **larger**  $C$  → more stored charge → smaller dip between peaks → smaller ripple.
- **larger**  $R$  → smaller load current → slower discharge → smaller ripple.
- **higher rectified frequency** (full-wave is twice the input) → less time to discharge between peaks → smaller ripple.

In short, a large  $RC$  compared with the time between peaks gives a smoother output.

### Purpose in summary

The smoothing capacitor reduces the ripple, giving a steadier d.c. voltage suitable for sensitive electronics.