

Rms values, transformers and power lines

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

Each answer shows the formula, the substitution and the result with its unit. When a problem gives an rms value, convert carefully to peak only if the question needs it. Small rounding differences in the last digit are acceptable.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.7.5

Problem 1 Peak from rms

$$V_0 = \sqrt{2} \times V_{\text{rms}} = 1.414 \times 120 = \mathbf{170 \text{ V}} \text{ (169.7 V)}.$$

Problem 2 Rms current

$$I_{\text{rms}} = I_0 / \sqrt{2} = 4.2 / 1.414 = \mathbf{2.97 \text{ A}} \text{ (about 3.0 A)}.$$

Problem 3 Period and frequency

$$T = 1/f. \text{ UK: } 1/50 = 0.020 \text{ s} = \mathbf{20 \text{ ms}}. \text{ Texas: } 1/60 = 0.01667 \text{ s} = \mathbf{16.7 \text{ ms}}.$$

Problem 4 Stove ring current

1. $I = P/V = 2300 / 230 = \mathbf{10 \text{ A}}.$
2. $R = V/I = 230 / 10 = \mathbf{23 \Omega}.$

Problem 5 Secondary voltage

$$V_s = V_p N_s/N_p = 230 \times 100 / 500 = \mathbf{46 \text{ V}}.$$

Problem 6 Meaning of rms

Over a full cycle the positive and negative halves cancel, so the mean is **zero** and says nothing about the supply. The rms value is the **steady dc value that gives the same heating effect** in a resistor.

Problem 7 High-voltage line data

1. $11 \text{ kV} = \mathbf{11\,000 \text{ V}}.$
2. $P = VI = 11\,000 \times 120 = \mathbf{1320000 \text{ W}} = 1.32 \text{ MW}.$

Problem 8 Currents in a transformer

1. $I_s = P/V_s = 36 / 12 = \mathbf{3.0\ A}$.
2. For an ideal transformer $V_p I_p = 36\ W$, so $I_p = 36 / 230 = \mathbf{0.157\ A}$ (0.16 A).

Problem 9 Efficiency

1. Efficiency = output / input = $72 / 80 = \mathbf{90\ \%}$.
2. Power wasted = 8 W, so $E = Pt = 8 \times 3600 = \mathbf{28800\ J}$ (28.8 kJ).

Problem 10 Loss in a village cable

1. $I = P/V = 100\ 000 / 2000 = 50\ A$; loss = $I^2 R = 50^2 \times 5.0 = \mathbf{12500\ W}$ (12.5 kW).
2. $I = 100\ 000 / 20\ 000 = 5\ A$; loss = $5^2 \times 5.0 = \mathbf{125\ W}$.
3. At 2.0 kV: **12.5 %**; at 20 kV: **0.125 %**.

Problem 11 Oscilloscope trace

1. Peak = 3.2 divisions $\times$ 5.0 V/div = **16 V**.
2. One cycle spans 4.0 divisions, so $T = 4.0 \times 5.0\ ms = 20\ ms$ and $f = 1/0.020 = \mathbf{50\ Hz}$.
3. $V_{rms} = 16 / \sqrt{2} = \mathbf{11.3\ V}$.

Problem 12 Power in a resistor

1. $V_{rms} = 30 / \sqrt{2} = \mathbf{21.2\ V}$.
2. $P = V_{rms}^2 / R = 450 / 40 = \mathbf{11.25\ W}$.
3. Peak power = $V_o^2 / R = 900 / 40 = \mathbf{22.5\ W}$. The power varies between zero and this value during each cycle, and its mean is exactly half the peak.

Problem 13 Why high voltage?

1. For the same power, a higher V means a smaller I. The cable loss is $I^2 R$, so it falls with the **square of the current**, and very little energy is wasted as heat.
2. Generators and homes need modest, safe voltages, so transformers step the voltage **up** before transmission and **down** before use. They only work with ac, which is one reason mains is alternating.

Problem 14 Laminated core

1. A solid block allows large eddy currents to circulate, heating the core. Thin insulated sheets **break up the eddy-current paths** and so reduce the heating.
2. Soft iron is easily magnetised and demagnetised, so the energy lost in each cycle (hysteresis) is small.

Problem 15 Ac and dc heaters

1. The same: **1.0 kW**, since rms is defined by equal heating.
2. $V_0 = \sqrt{2} \times 230 = \mathbf{325\text{ V}}$.
3. The voltage peaks at 325 V but is lower for most of the cycle, so the mean power equals that of a steady 230 V.

Problem 16 Village supply

1. $I = P/V = 440\,000 / 22\,000 = \mathbf{20\text{ A}}$.
2. $\text{Loss} = I^2 R = 20^2 \times 8.0 = \mathbf{3200\text{ W}}$ (3.2 kW).
3. $\Delta V = IR = 20 \times 8.0 = \mathbf{160\text{ V}}$.
4. Power delivered = $440\,000 - 3200 = 436\,800\text{ W}$, which is **99.3 %** of the power sent.

Problem 17 Real transformer

1. $I_s = P/V_s = 60 / 24 = \mathbf{2.5\text{ A}}$.
2. Input power = output / efficiency = $60 / 0.92 = \mathbf{65.2\text{ W}}$.
3. $I_p = P/V_p = 65.2 / 230 = \mathbf{0.28\text{ A}}$.

Problem 18 Instantaneous mains voltage

1. $V_0 = \mathbf{325\text{ V}}$; $\omega = 100\pi\text{ rad/s}$, so $f = \omega/2\pi = \mathbf{50\text{ Hz}}$.
2. $V = 325 \sin(100\pi \times 0.0040) = 325 \sin(1.257\text{ rad}) = 325 \times 0.951 = \mathbf{309\text{ V}}$.
3. $\sin(100\pi t) = 230/325 = 0.708$, so $100\pi t = 0.786\text{ rad}$ and $t = \mathbf{2.50\text{ ms}}$.

Problem 19 National grid design

1. $I = P/V = 200 \times 10^6 / 400 \times 10^3 = \mathbf{500\text{ A}}$; $\text{loss} = I^2 R = 500^2 \times 12 = \mathbf{3.0\text{ MW}}$.
2. At 25 kV, $I = 8000\text{ A}$ and the loss would be $8000^2 \times 12 = \mathbf{768\text{ MW}}$, which is more than three times the power station's output. This is impossible, so high-voltage transmission is essential.
3. $3.0 / 200 = \mathbf{1.5\%}$.

Problem 20 Spot the errors

1. $100/230 = 0.43\text{ A}$ is the **rms** current. The peak current is $\sqrt{2} \times 0.435 = \mathbf{0.61\text{ A}}$.
2. The ratio is upside down. $N_s = N_p V_s/V_p = 920 \times 12 / 230 = \mathbf{48\text{ turns}}$.
3. A step-down transformer must have fewer secondary turns than primary turns, so 17 600 turns is impossible.