

Transformers turns ratio and efficiency

AQA GCSE Separate Physics 8463 | Higher only | Paper 2 with supporting Paper 1 skills

Worked answers | Separate Physics Higher only | 28 parts | 46 marks

Specification points covered

4.7.3.4: transformer construction, operation, turns ratio and ideal power transfer

4.2.4.1: electrical power $P = VI$ and heating power $P = I^2R$

4.2.4.3: transformers and efficient transmission in the National Grid

4.1.2.2: efficiency from useful output power and total input power

A solar-powered field laboratory uses a battery and inverter to supply an instrument through a transformer. The inverter provides 48 V a.c. to the main transformer. You will select coil turns and check power, efficiency and current limits. Inverter losses are outside the transformer calculations.

Original PhysicsUK practice, not an official AQA resource. Whole sheet: Separate Physics Higher only, not Combined or Foundation. 28 parts, 46 marks. Repeatable ideal calculations lead to measured real-device comparisons. Credit equivalent wording and consistent follow-through; do not apply equal input/output power to a real unit without justification.

1 How the laboratory supply works

The battery supplies steady d.c. The inverter changes this to a.c. The transformer has insulated primary and secondary coils on a shared magnetic core. During normal use the secondary circuit is completed by the instrument.

1(a) Name the magnetic material normally used for a basic transformer core. **[1 mark]**

Answer / mark points: Iron. [1] Do not credit steel for the standard core in this model.

1(b) State the property of this material that makes it suitable for the core. **[1 mark]**

Answer / mark points: It is easily magnetised (and demagnetised). [1] Electrical conductivity is not the reason.

1(c) Explain why the inverter must supply an alternating current to the primary rather than a steady direct current for continuous transformer operation. **[3 marks]**

Answer / mark points: Alternating primary current produces a changing magnetic field in the core. [1]

The changing field through the secondary induces a p.d. across it. [1]

Steady d.c. would give a steady field, so no continuous induced secondary p.d. after switching transients. [1] Current flows in the secondary only when its circuit is complete.

1(d) A trainee says, "The primary current passes through the iron into the secondary." Explain why this is not how the instrument receives power. **[2 marks]**

Answer / mark points: The insulated coils form electrically separate circuits; primary current does not flow into the secondary. [1]

Energy is transferred by the changing magnetic field/electromagnetic induction, not a conducting link between coils. [1]



2 Selecting the coil turns

Figure 1 represents the main transformer. Its primary has 800 turns and is connected across 48 V a.c.; its secondary has 200 turns. The inverter and instrument are not drawn. Each pair of terminals connects only to its own external circuit. Winding counts in the drawing are schematic. Use the turns-ratio model for each separate trial.

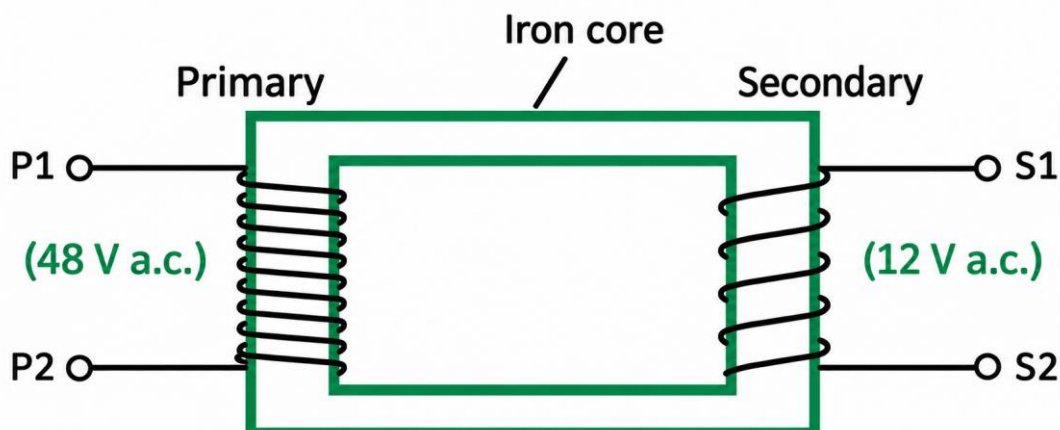


Figure 1

2(a) Calculate the main transformer's secondary p.d. and state whether it is step-up or step-down. **[2 marks]**

Answer / mark points: $V_s = V_p \times n_s/n_p = 48 \times 200/800 = 12 \text{ V}$. [1]

Step-down: its secondary p.d. is lower than its primary p.d. [1]

2(b) The same 48 V supply and 800-turn primary must now provide 24 V. Calculate the required secondary turn number. **[1 mark]**

Answer / mark points: $n_s = n_p \times V_s/V_p = 800 \times 24/48 = 400 \text{ turns}$. [1]

2(c) A calibration module has 360 primary turns and 90 secondary turns. Its secondary p.d. is 9.0 V. Calculate the primary p.d. **[1 mark]**

Answer / mark points: $V_p = V_s \times n_p/n_s = 9.0 \times 360/90 = 36 \text{ V}$. [1]



2 Selecting the coil turns continued

These are separate coil-design trials. Use each question's own voltages and turn numbers.

2(d) Another module has primary p.d. 60 V, secondary p.d. 15 V and 120 secondary turns. Calculate the primary turn number. **[1 mark]**

Answer / mark points: $n_p = n_s \times V_p/V_s = 120 \times 60/15 = 480$ turns. [1]

2(e) A 9.0 V sensor is supplied from 48 V using an 800-turn primary. Calculate the required secondary turn number. **[1 mark]**

Answer / mark points: $n_s = 800 \times 9.0/48 = 150$ turns. [1]

2(f) For the main 800-turn/200-turn transformer, a pupil calculates $V_s = 48 \times 800/200 = 192$ V. Explain the ratio error and give the correct result. **[2 marks]**

Answer / mark points: The pupil inverted the required secondary-to-primary turns fraction: V_s/V_p must equal n_s/n_p , not n_p/n_s . [1]

$V_s = 48 \times 200/800 = 12$ V. [1] Fewer secondary turns should reduce, not increase, p.d.

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3 Checking an ideal power model

Every transformer in this section is IDEAL: electrical power input equals electrical power output. Unless a question gives new conditions, the primary p.d. is 48 V and the secondary p.d. is 12 V. The instrument completes the secondary circuit.

3(a) The 12 V instrument draws 4.0 A from the secondary. Calculate its electrical power input. **[1 mark]**

Answer / mark points: $P = V_s I_s = 12 \times 4.0 = 48 \text{ W}$. [1]

3(b) For that 48 W output, calculate the current drawn from the 48 V primary supply by an ideal transformer. **[1 mark]**

Answer / mark points: Input power = output power = 48 W; $I_p = P/V_p = 48/48 = 1.0 \text{ A}$. [1]

3(c) The load now draws 5.0 A at 12 V. Calculate the ideal primary current at 48 V. **[1 mark]**

Answer / mark points: $P = 12 \times 5.0 = 60 \text{ W}$; $I_p = 60/48 = 1.25 \text{ A}$. [1] Alternatively $I_p = I_s \times V_s/V_p$.

3(d) For a fixed 60 W output, the secondary p.d. is increased from 12 V to 24 V. Calculate the new secondary current and explain why it is lower. **[2 marks]**

Answer / mark points: $I_s = 60/24 = 2.5 \text{ A}$. [1]

At fixed power, current is inversely proportional to p.d.; doubling p.d. halves current. [1] Do not assume fixed load resistance.

3(e) The secondary turn number of the main transformer is doubled, with primary conditions unchanged. If the output power is still 60 W, state the new secondary p.d. and current. **[2 marks]**

Answer / mark points: Secondary p.d. doubles to 24 V. [1]

Secondary current = $60/24 = 2.5 \text{ A}$. [1] The voltage and current do not both double at fixed power.

3(f) An ideal module has 800 primary turns, 100 secondary turns and a 48 V primary drawing 0.75 A. Calculate the secondary current, showing the intermediate voltage and power. **[3 marks]**

Answer / mark points: $V_s = 48 \times 100/800 = 6.0 \text{ V}$. [1]

$P = 48 \times 0.75 = 36 \text{ W}$, equal on both sides. [1]

$I_s = 36/6.0 = 6.0 \text{ A}$. [1] Allow consistent follow-through.



4 Testing real transformers

Table 1 gives steady loaded readings for two REAL units at the transformer terminals. Useful output power is the electrical power supplied to the instrument. Use $P = VI$ for these readings. The instrument needs 60 W at 12 V.

Table 1

Unit	V_p / V	I_p / A	V_s / V	I_s / A
Real A	48	1.50	12	5.00
Real B	48	1.25	12	4.50

4(a) Calculate the electrical power input to real unit A. **[1 mark]**

Answer / mark points: $P_{\text{input}} = 48 \times 1.50 = 72 \text{ W}$. [1]

4(b) Calculate the useful electrical power output from real unit A. **[1 mark]**

Answer / mark points: $P_{\text{output}} = 12 \times 5.00 = 60 \text{ W}$. [1]

4(c) Calculate unit A's efficiency as a decimal and as a percentage. **[2 marks]**

Answer / mark points: Efficiency = $60/72 = 0.833\ldots$. [1]

Efficiency = 83.3% (about 83%). [1] Useful output goes on top, not input.

4(d) Calculate the rate of unwanted energy transfer in unit A. Include the unit. **[1 mark]**

Answer / mark points: $72 - 60 = 12 \text{ W}$. [1] This is a power, not an energy of 12 J.

4(e) An ideal model predicted a primary current of 1.25 A for the same 60 W output. Why does real unit A draw 1.50 A instead? **[1 mark]**

Answer / mark points: Extra input power is needed because some energy is transferred to the surroundings, for example by heating the coils/core. [1] Output power alone is less than input power.

4(f) Calculate unit B's efficiency. A trainee chooses B because it is more efficient than A. Use its output power to decide whether it meets the instrument's 60 W requirement at the recorded operating point. **[3 marks]**

Answer / mark points: Input = $48 \times 1.25 = 60 \text{ W}$; output = $12 \times 4.50 = 54 \text{ W}$. [1 for both]

Efficiency = $54/60 = 0.90 = 90\%$. [1]

It is more efficient but does not meet the stated requirement: 54 W is below 60 W. [1] Efficiency alone is not the selection criterion.



5 Making the final design decision

The main supply is 48 V a.c. and its primary-current limit is 1.40 A. The instrument needs 60 W at 12 V. A proposed replacement transformer is 96% efficient at this output. Check only the stated electrical criteria, not full engineering safety.

5(a) A backup inverter supplies 36 V to a 900-turn primary. Choose a secondary of 150, 300 or 600 turns to supply 12 V. Show the ratio calculation. **[1 mark]**

Answer / mark points: $n_s = 900 \times 12/36 = 300$ turns. [1]

5(b) Return to the main 48 V supply and 60 W output. Calculate the ideal primary current and decide whether it is below the 1.40 A limit. **[2 marks]**

Answer / mark points: Ideal $I_p = 60/48 = 1.25$ A. [1]
1.25 A is below 1.40 A, so the ideal model meets the limit. [1]

5(c) Does REAL unit A in Table 1 meet that same current limit? Justify your answer using its measured current. **[1 mark]**

Answer / mark points: No: its measured primary current is 1.50 A, greater than 1.40 A. [1 for decision with evidence] The ideal prediction must not replace the measured value.

5(d) The proposed replacement delivers 60 W at 96% efficiency. Calculate its input power and primary current at 48 V, then decide whether it meets the limit. **[3 marks]**

Answer / mark points: Input power = $60/0.96 = 62.5$ W. [1]
 $I_p = 62.5/48 = 1.302\dots$ A, about 1.30 A. [1]
It meets the stated current limit because 1.30 A is below 1.40 A. [1] This is not a complete safety approval.

5(e) The lab models a remote supply with 60 W ENTERING a cable. Compare a 48 V and a 240 V transmission p.d. Calculate the current in each case, using $P = VI$. **[2 marks]**

Answer / mark points: At 48 V: $I = 60/48 = 1.25$ A. [1]
At 240 V: $I = 60/240 = 0.25$ A. [1] These values refer to power entering the cable, not power delivered after losses.

5(f) The total cable resistance is 2.0Ω in each case. Use $P = I^2R$ to calculate the heating loss at each transmission p.d., then relate the comparison to the National Grid. **[3 marks]**

Answer / mark points: At 48 V: loss = $1.25^2 \times 2.0 = 3.125$ W (about 3.1 W). [1]
At 240 V: loss = $0.25^2 \times 2.0 = 0.125$ W (about 0.13 W). [1]
A higher transmission p.d. means smaller current for the same transmitted input power, so less heating loss; this explains the use of step-up transformers in the National Grid. [1] Loss is 25 times smaller here.

Review and improve

Keep the voltage/turns ratio distinct from the inverse ideal current ratio. Check model boundaries and current limits. Timing is estimated and untrials.

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