YEAR 12 PHYSICS, UNIT 4

Power Transmission, Wave-Particle Duality and Quantum Test

NAME: ______________________________

TOTAL MARKS: /61

TIME ALLOWED FOR THIS PAPER

Working time for paper: 55 minutes

INSTRUCTIONS TO CANDIDATES

Answer all questions.

Sufficient working should be shown on all calculation, with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at. Correct answers which do not show full working will not necessarily be awarded full marks.

Give final answers to three significant figures, using scientific notation if needed, and include appropriate units where applicable.

When estimating numerical answers or reading information from a chart or graph, give final answers to a maximum of two significant figures and include appropriate units where applicable. Clearly state any assumptions or estimations which are made.

Question 1 **[5 Marks]**

Rayleigh-Jeans Law states that the intensity of radiation emitted from a black body is directly proportional to the temperature ($I \propto T$)) and inversely proportional to wavelength raised to the fourth power ($I \propto \frac{1}{\lambda^4}$). This led to an early problem known as the Ultraviolet Catastrophe, wherein the classical physics prediction (Rayleigh-Jeans Law) did not agree with experiment and observation.

a) State the details of this disagreement (i.e., what did the theory predict and what did the evidence show?): (3)

The classical theory (Rayleigh-Jeans Law) predicted that, at low wavelengths (or high frequencies) the intensity of emitted radiation → ∞. (1)

Through experiment and observation, we know that black body radiators do not emit infinite energy/intensity in any part of the spectrum. (1)

Black body radiators have been observed to have peak frequencies/wavelengths of emission, where the intensity of radiation decreases either side of the peak. Classical theory could not account for this. (1)

b) Max Planck was able to resolve the discrepancy between theory and experiment. State the assumption(s) he made that allowed him to do this, and how this affected our understanding of electromagnetic radiation:

Planck assumed that electromagnetic radiation (light) can only be absorbed and emitted in discrete amounts, or *quanta*. (1)

Planck was able to show that this assumption allowed for the observed results to be accurately predicted. Consequently, he provided evidence for the particle-nature of electromagnetic radiation (light). (1)

Question 2 **[3 marks]**

A radio transmitter uses a metallic aerial to broadcast a signal. It does this by oscillating electrons in the aerial, producing 2.05 x 10^{30} photons per second. The radio transmission has a wavelength of 680 m. Determine the power of the radio transmitter (to the nearest hundred Watts).

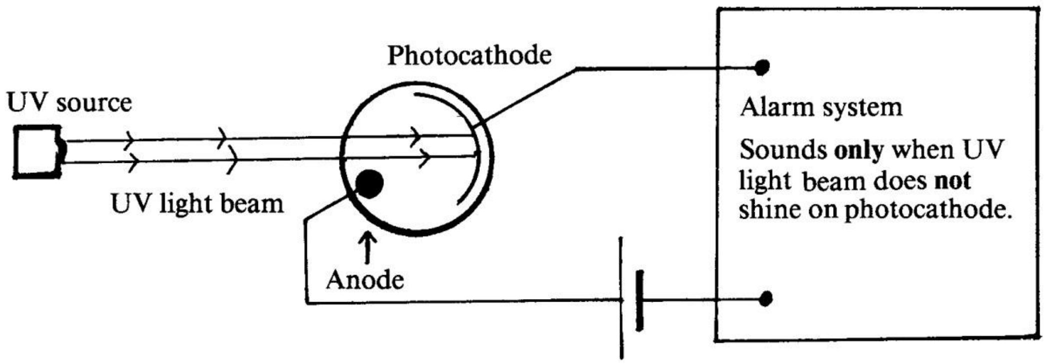
$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{680} = 4.41 \times 10^5 \, Hz \quad (1)$$

$$E = hf = (6.63 \times 10^{-34})(4.41 \times 10^5) = 2.92 \times 10^{-28} \, J/photon \quad (1)$$

$$P = E_{photon} \times no. of\ photons\ per\ second = (2.92 \times 10^{-28}) \times (2.05 \times 10^{30}) = 598.6 = 600 \, W \quad (1)$$

Question 3 **[4 marks]**

The diagram below shows part of the circuit for a burglar alarm.



The alarm system is arranged in such a way that, when ultra-violet (UV) light shines on the photocathode, the alarm does **not** sound but when the UV light beam is broken the alarm will start to sound.

a) Which of the statements (A-D) below is the best explanation of the effect of shining UV light on the photocathode? Circle one statement. (2)

A The UV light photons eject electrons from the photocathode causing an electric current to flow in the circuit.

B The UV light photons eject positive charges from the photocathode causing an electric current to flow in the circuit.

C The UV light prevents electrons from being ejected from the photocathode, hence the alarm sounds only when the beam is broken.

D The UV light deflects electrons which normally flow from the photocathode to the anode.

The ultra-violet light source is now replaced by a source of red light.

b) Which of the statements (A-D) below best describes the result of this replacement? Circle one statement. (2)

A The alarm will definitely operate as normal.

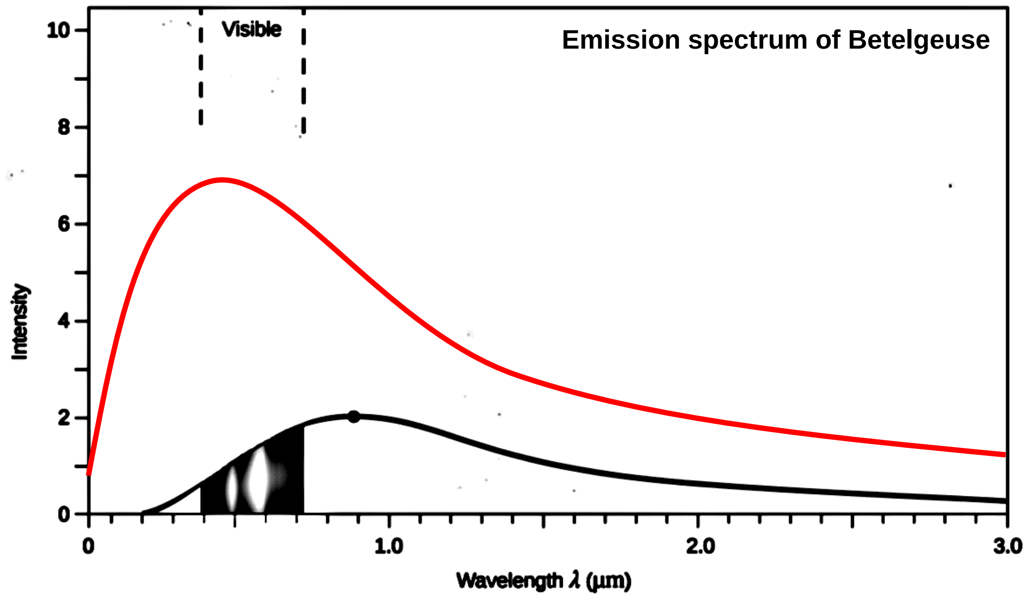
B The alarm will now ring whether or not the light beam is broken.

C The alarm will now ring when the light beam is shining but will stop when the beam is broken.

D Whether or not the alarm will operate normally depends on the value of the work function of the photocathode material.

Question 4 **[3 Marks]**

The electromagnetic spectrum of the star Betelgeuse is shown below. Like most stars, the spectrum is very close to that of an ideal black body radiator. The range of wavelength of visible light is shown by the vertical column.



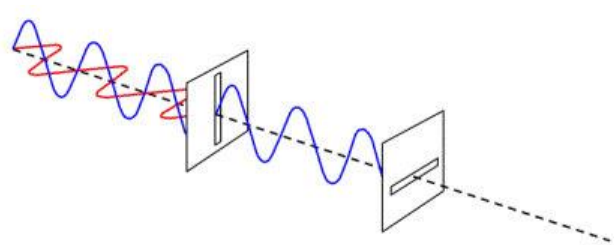
a) What (visible) colour would you expect Betelgeuse to appear? ___Red_______ (1)

b) Betelgeuse' neighbouring star Bellatrix has a much hotter surface temperature. Draw a curve on the graph above to show a possible spectrum of Bellatrix. (2)

Lower Peak λ (1) : Higher Intensity across all λ (1)

Question 5 **[4 Marks]**

Describe the phenomenon of polarization and explain briefly, with reference to the diagram, how it supports the wave model for light.



Polarization refers to the orientation of the electric/magnetic field associated with a wave. It describes the direction in which the electric/magnetic field oscillates as the wave propagates. (1)

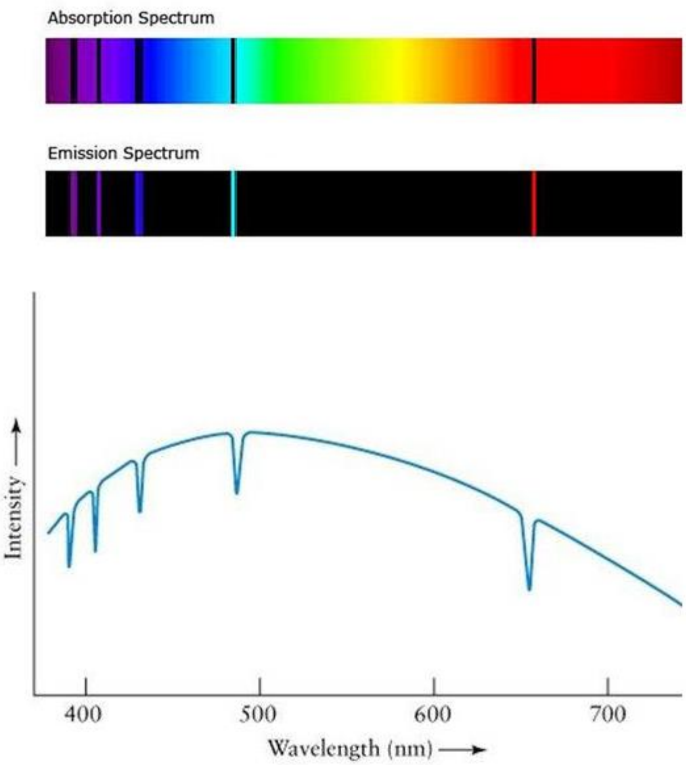
The diagram shows unpolarized light becoming polarized when passing through a polaroid filter. (1)

The second filter is oriented at right-angles to the first, preventing the light from going any further. (1)

This demonstrates that light behaves like a transverse wave, supporting the wave model for light. (1)

Question 6 **[9 marks]**

Pictured below is an example of a spectrum graph, above which we see both an absorption and emission spectrum for the same element. Measurements for this graph were made using astronomical spectroscopy observations of a nearby stellar cluster.



a) Does the spectrum graph represent an absorption or emission spectrum? (1)

Absorption Spectrum

b) An astrophysicist could identify the element through analysis of the graph. Explain how this is possible. (4)

The dipped intensity spikes represent wavelengths of light that have been absorbed by electron transitions. (1)

The energy of these transitions is measurable from the graph (1) and unique to each element (1).

An astrophysicist could compare this information to known samples in a laboratory and thus determine the element (1).

c) Two physics students disagree on what the spectrum graph represents. The first asserts that the graph reveals the elemental composition of a nearby star in the stellar cluster. The second argues that the graph shows the elemental composition of a gaseous nebula or planetary atmosphere located between the stellar cluster and Earth. Which student is most likely to be correct? (4)

Stars may be considered Blackbody radiators emitting a continuous spectrum. (1)

The graph represents a continuous spectrum with characteristic wavelengths having been absorbed out (1), indicating that the light has passed through a gaseous substance (1).

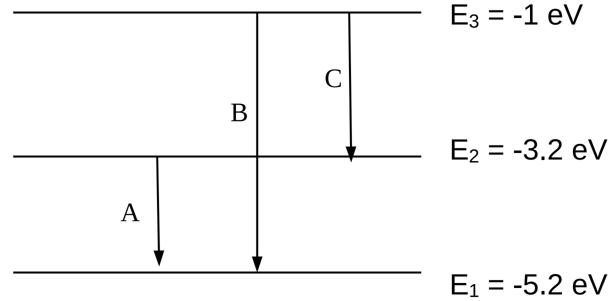
Therefore, the second student is most likely correct (1).

Question 7 **[4 Marks]**

An aurora is the appearance of coloured "curtains" of light in the sky near the Earth's poles. The light comes from the atoms high in the atmosphere which have been "excited" by streams of charged particles entering the atmosphere from the sun or from the Earth's radiation belts. The green colour in an aurora is due to the emission from excited oxygen atoms and has a wavelength of 565 nm.

Part of the energy level diagram for oxygen is shown on the right:

Which electron transition (A, B or C) is responsible for the green light? (Show all calculations and reasoning).



$$E = hf = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^{8})}{565 \times 10^{-9}} \quad (1)$$

$$= 3.52 \times 10^{-19}\, J \quad (1)$$

Convert to eV:

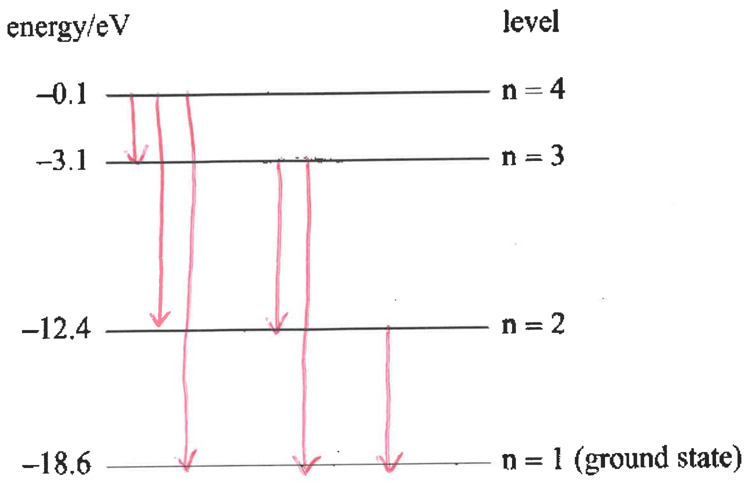
$$3.52 \times 10^{-19} \div 1.60 \times 10^{-19} = 2.20\, eV \quad (1)$$

This is the size of the gap between E_3 → E_2 , ∴ $\boxed{\text{C}}$ (1)

Question 8 **[5 Marks]**

The diagram shows some energy levels, in eV, of an atom.

a) How many emission lines are possible in total between these energy levels? (1)



$\boxed{6}$

b) What is the ionisation energy, in eV, for an electron in the ground state? (1)

$\boxed{18.6\ eV}$

In its ground state, the atom is bombarded by an incident *electron* with 2.1 x 10^{-18} J of energy.

c) Calculate the possible energies, in eV, with which this incident electron could be scattered from the atom after the collision. (3)

Energy of Incident Electron : $E = \frac{2.1 \times 10^{-18}}{1.60 \times 10^{-19}} = 13.125\ eV$ ✓

$n = 1 \rightarrow 3$: $E = -3.1 - (-18.6) = 15.5\ eV$ (not enough energy for this to occur).

$n = 1 \rightarrow 2$: $E = -12.4 - (-18.6) = 6.2\ eV$ (could occur).

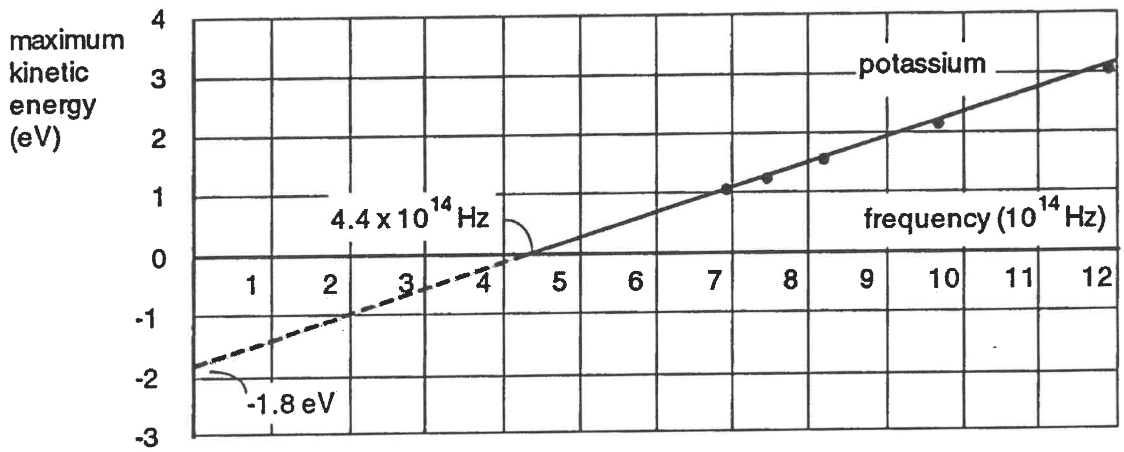
Remainder : $13.125\ eV - 6.2\ eV = 6.925\ eV$

$\therefore$ Possible scattered energies : $\boxed{13.125\ eV \text{ or } 6.925\ eV}$ ✓ ✓

Question 9 **[8 marks]**

In early experiments to investigate the photoelectric effect, a beam of light of a single frequency was directed at a clean surface of potassium metal. The maximum kinetic energy of electrons which were ejected from the metal was measured.

When the experiment was repeated with different frequencies of light the maximum kinetic energy of electrons depended on the frequency of the light as shown below.



a) What is the minimum energy of a light photon that can eject an electron from potassium metal? (Answer in units of eV) (1)

$\boxed{1.8\,eV}$

The graph above shows that electrons ejected by light of frequency 6.0 x 10^{14} Hz have a maximum kinetic energy of 0.7 eV. The maximum kinetic energy of electrons ejected by light of frequency 1.2 x 10^{15} Hz is 3.2 eV

b) Explain why the maximum kinetic energy of electrons ejected by light of a higher frequency is greater than the maximum kinetic energy of electrons ejected by light of a lower frequency. (2)

- The KE of a photoelectron is the energy remaining after it has escaped the metal surface ($KE_{max} = hf - \phi$).
- Since high frequency photons have more energy ($E=hf$), they can provide more energy to electrons when absorbed.

c) Light of frequency 9 x 10^{14} Hz is shone on the sample and the potential bias is reversed. Calculate the minimum reverse bias needed to stop the photo current (i.e. the stopping voltage). (3)

$E = hf - \phi$

$E = Vq$

$\therefore Vq = hf - \phi$ ✓

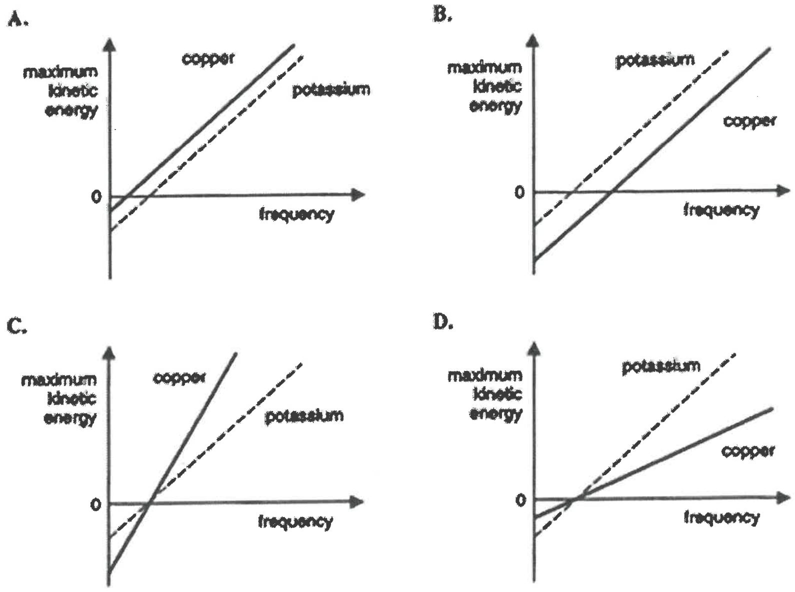
$\therefore V = \frac{hf - \phi}{q}$

$V = \frac{(6.63\times10^{-34})(9\times10^{14}) - (1.8)(1.6\times10^{-19})}{1.6\times10^{-19}}$ ✓

$\boxed{V = 1.93\,V}$ ✓

The minimum photon energy required to eject electrons from copper is approximately double the value for potassium.

d) Which of the graphs below would best describe the results if the experiment were repeated with copper instead of potassium? Explain your choice, commenting on the slope of the lines for potassium and copper and the points where the lines cross the frequency axis. (2)



Answer: B ✓

Explanation: Slopes must be the same (h),

Threshold frequency (x-int) is double for Copper.

✓ OR Work function (y-int) is double for Copper

Question 10 **[5 Marks]**

A 650 nm laser is shone through a diffraction grating.

a) Calculate the momentum of a photon fired from this laser. (1)

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{650 \times 10^{-9}} = 1.02 \times 10^{-27}\ kg.m/s$$

b) Determine the speed at which an electron would need to move in order to achieve the same de Broglie wavelength as the photon. (2)

$$\lambda = \frac{h}{p} = \frac{h}{mv} \rightarrow v = \frac{h}{m\lambda} \qquad (1)$$

$$v = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(650 \times 10^{-9})} = 1.12 \times 10^{3}\ m/s \qquad (1)$$

c) The four statements below relate to de Broglie's postulate. One of them is incorrect. Identify this statement and re-write it correctly. (2)

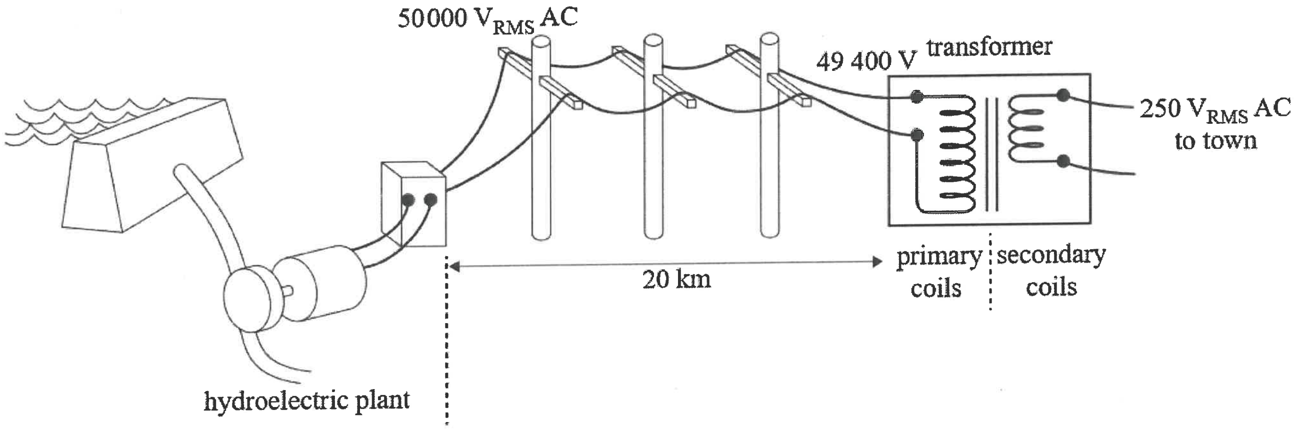
1. It suggested a reason for Bohr's quantisation of electron energy levels in atoms.
2. It suggested that electrons in atoms can be considered as standing waves
3. It explained why electrons have momentum (1)
4. The location of particles in motion can be considered 'spread out' over a distance rather than located at a particular point.

It explained why ***photons*** have momentum. (1)

*Stating, "It did not explain why electrons have momentum" is an invalid trivial response.

Question 11 **[11 Marks]**

A small town is supplied with electricity from a smal hydroelectric generation plant about 20 km from the town. Electricity is transmitted through a high-voltage transmission lines. The voltage supplied at the generator end is 50 000 volts (RMS). The RMS current in the lines is 15 amperes. At the edge of town a substation transformer converts this to 250 V. This is shown in the figure below.



a) Calcuate the power supplied by the plant. (1)

$P = VI = 50000 \times 15 = \boxed{7.50 \times 10^5 \text{ W}}$

b) The voltage that is delivered to the substation transformer is 49 400 V. Calculate the total resistance of the transmission lines. (2)

$R = \frac{V_{drop}}{I} = \frac{50000 - 49400}{15} = \boxed{40.0\,\Omega}$ ✓ ✓

c) The primary coil in the substation transformer has 9880 turns. Calculate the number of turns in the secondary coil (assume no power loss). (2)

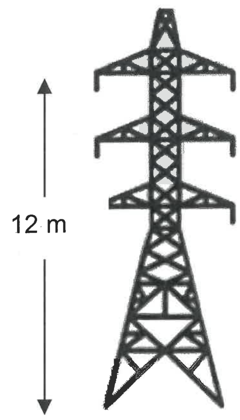
$\frac{V_p}{V_s} = \frac{N_p}{N_s} \Rightarrow \frac{49400}{250} = \frac{9880}{N_s}$ ✓

$\therefore \boxed{N_s = 50}$ ✓

d) The high voltage transmission lines are held by towers at a height of 12 m. Calculate the mean magnitude of the magnetic field that would be experienced at ground level due to the 15 A overhead current. (2)

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}) \times 15}{2\pi \times 12} ✓$$

$$= \boxed{2.50 \times 10^{-7}\ T} ✓$$



e) Some townspeople are concerned about the high voltage towers and their associated magnetic fields. They suggest that the power could be more safely supplied at a lower voltage. Clearly explain why this would result in large losses of energy. (3)

$P = VI$. In order to deliver the same power at a lower voltage, current would need to be increased. ✓

However, $P_{Loss} = I^2 R$ (R = resistance, I = current). ✓

Therefore, increasing the current will increase the amount of power lost by a factor of the square of the current. ✓

f) Calcuate the peak voltage of the town supply. (1)

$$V_{rms} = \frac{V_{max}}{\sqrt{2}} \Rightarrow V_{max} = \sqrt{2}\, V_{rms}$$

$$= \sqrt{2} \times 250$$

$$= 353.6\ V \text{ or } \boxed{3.54 \times 10^2\ V} ✓$$

END OF TOPIC TEST