IB · DP · Physics

3 hours 15 questions

Structured Questions

8.2 Thermal Energy Transfer

8.2.1 Conduction, Convection & Thermal Radiation / 8.2.2 Black-Body Radiation / 8.2.3 The Solar Constant, Albedo & Emissivity / 8.2.4 The Greenhouse Effect / 8.2.5 Earth's Surface–Atmosphere System

Easy (5 questions)	/47
Medium (5 questions)	/60
Hard (5 questions)	/47
Total Marks	**/154**

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Easy Questions

1 (a) A takeaway drinks company are investigating different recyclable and reusable materials to keep both hot and cold drinks at a drinkable temperature for longer. Thermal energy transfers from hotter areas to cooler areas.

(a) Place a tick (✓) next to the processes that transfer thermal energy.

Conduction	
Convection	
Expansion	
Radiation	
Rotation	

[3]

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.....

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(3 marks)

(b) The drinks company are trying to understand more about conduction.

(b) Use the words below to complete the sentences to explain the process of conduction.

solids	**metals**	**gases**
hotter	**cooler**	**liquids**
plastics	**paper**	**wood**

(i) Conduction is the main method of thermal transfer in _____.

[1]

(ii) Two solids of different temperatures come in contact with one another and thermal energy is transferred from the _____ object to the _____ object.

[1]

(iii) _____ are the best thermal conductors.

[1]

(3 marks)

(c) Convection currents occur within fluids. The drinks company is trying to understand how a convection current could occur in a hot drink if heated from below.

(c) Number the statements below from 1 - 4 to show the correct order for how a convection current forms in a hot drink.

	The hotter part of the fluid becomes less dense than the surrounding fluid.
	The hot fluid rises, and the cooler (surrounding) fluid moves in to take its place.
	The heated molecules gain kinetic energy and push each other apart, making the fluid expand.
	The hot fluid cools, contracts and sinks back down again.

[4]

(4 marks)

(d) The drinks company are looking into reducing the thermal radiation emitted from their cups.

(d) Place a tick (✓) next to the correct statements about thermal radiation.

All bodies, no matter what temperature, emit a spectrum of thermal radiation	
The cooler the object the more infrared radiation it emits in a given time	
Thermal radiation requires matter to propagate	
The higher the temperature of an object the greater the thermal motion of its atoms	

[2]

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(2 marks)

2 (a) Astronomers are investigating black body radiation.

(a) Define black body radiation by using the correct words to complete the gaps in the sentence below.

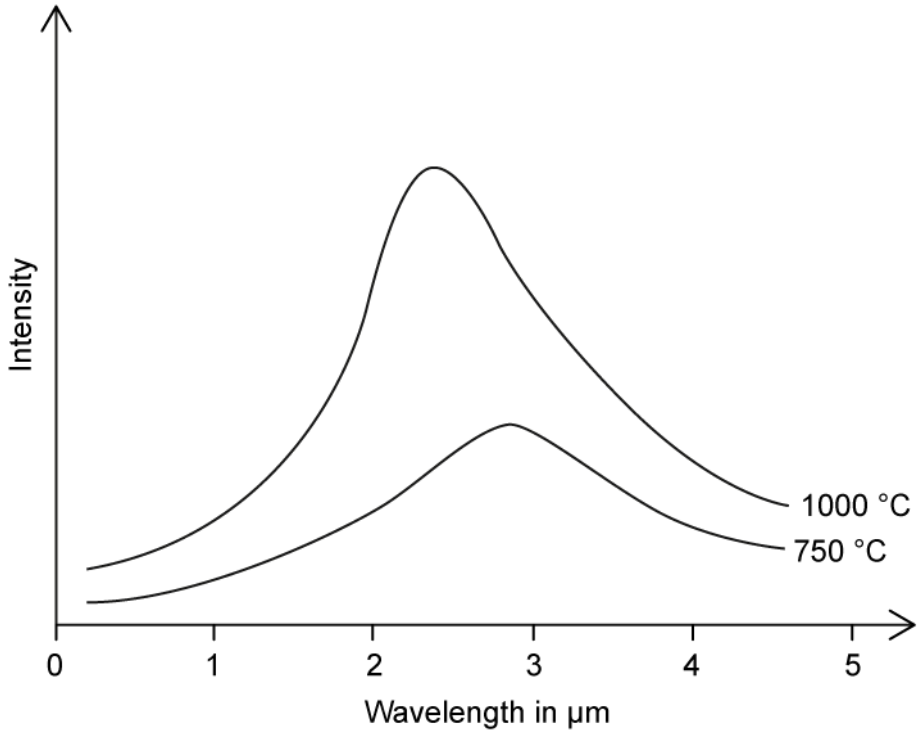
An object that _____ all of the radiation incident on it and does not _____ or transmit any radiation.

[2]

(2 marks)

(b) The graph below shows a black body radiation curve.

(b) Identify, by drawing a line, the peak intensity of the radiation.



[2]

(2 marks)

(c) One of the stars the astronomers are observing emits radiation with a maximum wavelength $\lambda_{max} = 900 \times 10^{-9}$ m.

(c) Use Wien's displacement law to calculate the temperature of the star.

[3]

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(3 marks)

(d) The Stefan-Boltzmann Law states that the power output of a black body depends on two factors.

(d) Place a tick (✓) next to the two correct factors.

Mass	
Radius	
Surface temperature	
Core temperature	

[2]

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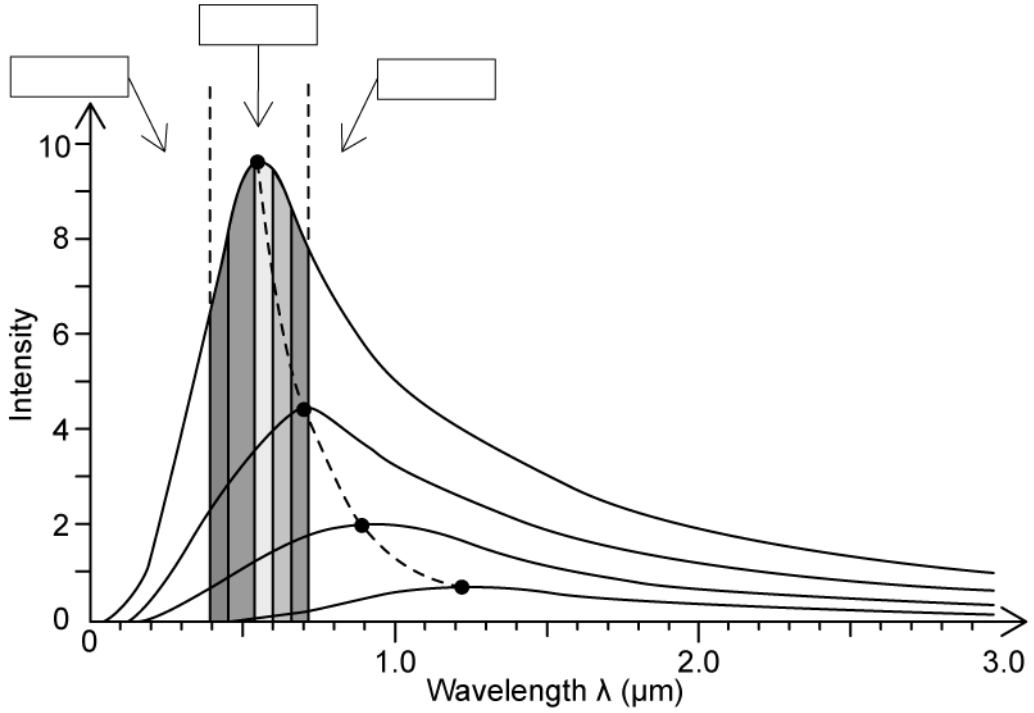
(2 marks)

3 (a) Astronomers are using Wien's Law to predict the temperature of different stars. The intensity-wavelength graph below shows how thermodynamic temperature links to the peak wavelength for four different bodies.

(a) Identify the visible, ultraviolet and infrared wavelengths by correctly labelling the sections of the graph.



[2]

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(2 marks)

(b) (b) Identify the statements that are associated with Wien's Law, by placing a tick (✓) in the correct box.

The lower the temperature of a body, the shorter the wavelength it emits at the peak intensity.	
The black body radiation curve for different temperatures peaks at a wavelength which is inversely proportional to the temperature.	
The higher the temperature of a body, the greater the intensity of the radiation at each wavelength.	
The minimum wavelength is proportional to $\frac{1}{T}$.	

[2]

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(2 marks)

(c) The astronomers are considering the Earth's surface-atmosphere system and whether this will affect the calculated temperature of stars detected on Earth.

(c) Use the text in the box to complete the sentences below, describing the Earth's Surface-Atmosphere system.

Carbon monoxide	**transfer**	**Sun**
Greenhouse gases	**constant**	**space**

(i) The Earth's energy balance depends on how much energy is incoming from the _____ and how much energy is returned to _____.

[1]

(ii) If incoming and outgoing energy are in balance, the Earth's temperature will remain _____.

[1]

(iii) This system can be used to create models that help climate scientists predict temperature fluctuations based on concentrations of _____ _____.

[1]

.....

(3 marks)

(d) The equation for The Stefan-Boltzmann Law is:

$$P = \sigma A T^4$$

(d) Calculate the total power emitted by a star when the surface area is 4×10^{20} m^3 and the absolute temperature 4500 K.

[2]

(2 marks)

4 (a) Environmentalists are considering the Sun's rays and the amount of energy received at the surface of the Earth's atmosphere.

(a) Define the solar constant by placing a tick (✓) in the correct box.

The amount of solar radiation across visible wavelengths that is incident in one second on one square meter at the mean distance of the Earth from the Sun	
The amount of solar radiation across all wavelengths that is incident in one minute on one square meter at the mean distance of the Earth from the Sun	
The amount of solar radiation across all wavelengths that is incident in one second on one square meter at the mean distance of the Earth from the Sun	
The amount of solar radiation across all wavelengths that is incident in one second on one square meter at the maximum distance of the Earth from the Sun	

[1]

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(1 mark)

(b) The solar constant varies year-round for two main reasons.

(b) State the two reasons by completing the gaps in the sentences below.

(i) The Earth has an _____ orbit around the Sun.

[1]

(ii) The Sun's output _____ during its 11-year sunspot cycle.

[1]

.....

.....

(2 marks)

(c) In an experiment looking at solar energy, the total incident power is 1500 W. The albedo of green grass is 0.25.

(c) Calculate the total scattered power when this light is incident on green grass.

[2]

(2 marks)

(d) Emissivity relates objects to a black body.

(d) Choose the correct statements about emissivity by placing a tick (✓) next to them.

Calculations of the emissivity assume that the black body is at the same temperature as the object	
Calculations of the emissivity assume that the black body has smaller dimensions than the object	
For a perfect black body, emissivity is equal to 1	
Emissivity = $\frac{\text{total scattered power}}{\text{total incident power}}$	

[3]

(3 marks)

5 (a) Climate change scientists are looking to reduce the number of greenhouse gasses in the atmosphere.

(a) Identify the gases that are greenhouse gases by placing a tick (✓) next to them.

Carbon monoxide	
Carbon dioxide	
Methane	
Sulphur dioxide	

[2]

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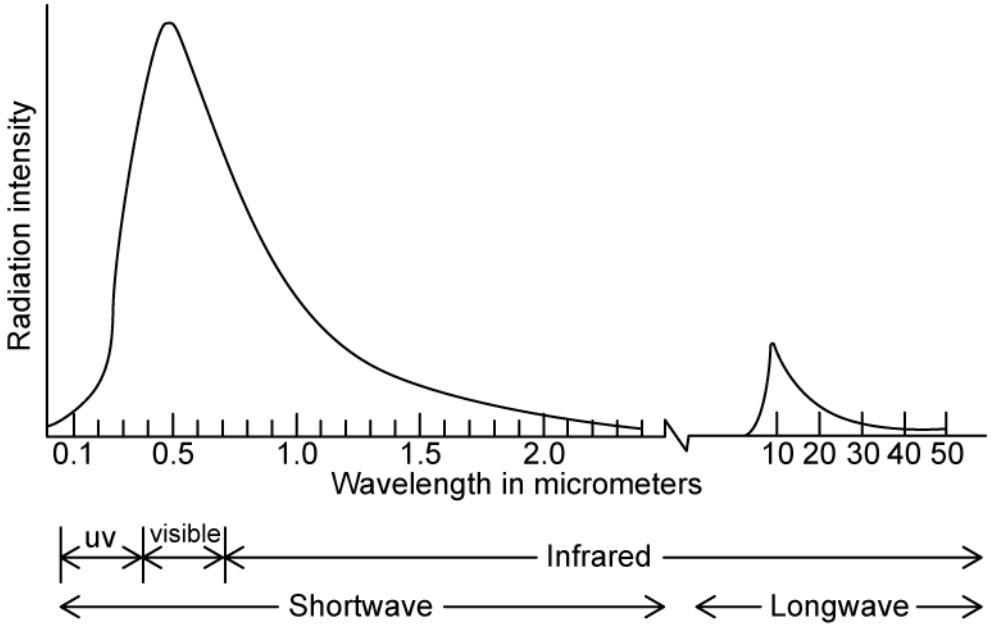
(2 marks)

(b) Greenhouse gases have a natural frequency that falls within one region of the electromagnetic spectrum.

(b) Use the graph to identify this region.



[1]

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(1 mark)

(c) There are many mechanisms that can increase the effect of global warming.

(c) Use the words below to complete the sentences to explain how the rate of global warming can be increased.

decrease	**insoluble**	**increase**
carbon dioxide	**emissivity**	**heat absorption**
carbon monoxide	**evaporate**	**solubility**
melt	**albedo**	**water vapour**

(i) Ice and snow will melt leading to a _____ in _____ and hence, an increased rate of _____ _____.

.

[1]

(ii) The _____ of carbon dioxide in the sea will decrease, leading to an increase in atmospheric _____ _____ concentration.

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[1]

(iii) Surface water will _____. This will lead to an increase in atmospheric _____ _____ concentration.

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[1]

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(3 marks)

(d) As a result of small increases in the temperature of the Earth runaway chain reactions can cause catastrophic climate change.

(d) Identify these chain reactions by placing a tick (✓) next to them.

Rise in sea level due to the melting of ice	
Fall in sea level due to the evaporation of seawater	
Heatwaves	
Heavy Flooding	
Tornadoes	

[3]

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(3 marks)

Medium Questions

1 (a) Thermal radiation is emitted by all bodies with an absolute temperature. It is often modelled using an idealised 'black body'.

(a) Explain how the temperature of a black body can be estimated based on the frequency of radiation emitted from it.

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(2 marks)

(b) The spectrum of radiation emitted by a sample of glacier ice is examined. The ice is at a temperature of –55 °C.

(b) Calculate the peak wavelength of radiation emitted by the ice.

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(2 marks)

(c) The average albedo of clean snow is 0.9. The average albedo of the glacier ice is 0.25.

(c) For the glacier:

(i) Determine the ratio of radiation scattered from the snow compared to the glacier ice

[2]

(ii) Outline an assumption made in part (i) and give a reason why this assumption may not be correct.

[2]

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(4 marks)

(d) The average intensity of radiation incident on the glacier is 4.7 kW h m^{-2} during the summer and 0.23 kW h m^{-2} during the winter, but these values are expected to rise as the climate changes.

When the snow melts and exposes the glacier ice beneath the surface albedo falls. This process is being accelerated. Explain how this acceleration affects global warming.

(3 marks)

2 (a) An industrial kiln is used for 'firing' ceramic and pottery items at very high temperatures.

The kiln emits electromagnetic radiation of peak wavelength, $\lambda_{max} = 3.50 \times 10^{-6}$ m.

(a) Determine the temperature, in degrees Celsius, of the kiln. You can treat the kiln as an ideal black body.

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(2 marks)

(b) The kiln has a surface area of 160 m^2.

(b) Calculate the energy radiated per second.

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(3 marks)

(c) The large kiln is compared to a smaller model with a surface area of 120 m^2 and a lower operating temperature of 710 K. The smaller kiln is made from the same materials and can also be treated as an ideal black body.

(c) Determine the ratio of power radiated for the large kiln to the small kiln.

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(2 marks)

(d) The working areas and people around kilns need to be protected from the high levels of heat energy emitted.

(d) With reference to the mechanisms by which heat energy is transferred, outline how protection from heat energy could be achieved.

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(3 marks)

3 (a) (a) The intensity of radiation from a source radiating energy at a rate of P follows an inverse square law with the distance, r, from the source.

(i) Derive an expression for intensity of this radiation at distance, r, from the source.

(ii) Outline an assumption made in part (i).

(3 marks)

(b) A planned Mars Rover will be powered using several solar panels each with dimensions of 2800 × 5900 mm. The equipment is tested on Earth at a point where the albedo of Earth's atmosphere is 0.310.

The radiant power of the Sun is 3.90×10^{26} W and the average radius of Earth's orbit around the Sun is 1.50×10^{11} m.

(b) Determine the power, in kW, incident on a single solar heating panel being tested on Earth.

Assume that the Sun is at its highest point and the light from the Sun is normally incident on the panel.

(4 marks)

(c) An astronomer uses the following data for a simple climatic model of Mars without an atmosphere:

Orbital radius between Mars and the Sun = 2.3×10^{11} m

Absorbed solar radiation = 493 W m^{-2}

(c) Determine the average albedo for Mars that is to be used in the modelling.

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(2 marks)

(d)

(d) Determine the ratio $\frac{P_M}{P_E}$

Where P_M is the power of solar radiation incident on the solar panel on Mars and P_E is the power of solar radiation incident on the solar panel on Earth.

[2]

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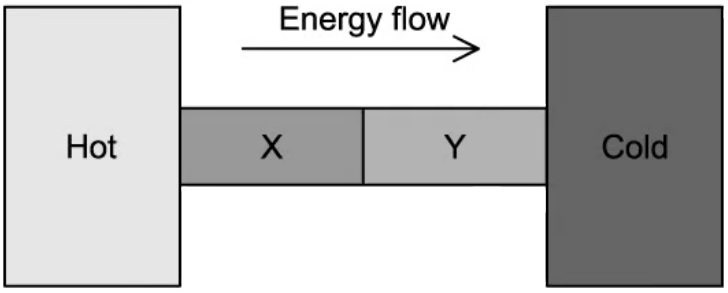
(2 marks)

4 (a) A regular cylinder is made up from two materials, X and Y. The cylinder's dimensions are uniform throughout X and Y. The cylinder is placed in contact with a hot and cold source such that energy is conducted between them.



(a) State and explain whether the following values are equal for the cylinder:

(i) The energy flow rates through X and Y

[2]

(ii) The temperature difference across X and the temperature difference across Y.

[2]

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(4 marks)

(b) The following data are available for two metallic elements.

Silver	**Gold**
Density = 10.49 g cm^{-3}	Density = 19.3 g cm^{-3}
Relative atomic mass = 107.8682	Relative atomic mass = 196.9665

(b)

Using the data, and by determining a suitable equation, determine whether silver or gold is a better conductor of electricity.

Assume that each metal atom contributes one free electron.

(4 marks)

(c) It is very common at the coast for beaches to experience onshore winds during the day and offshore winds at night.

(c) Outline why this might be the case.

(4 marks)

(d) A satellite orbiting Earth has a malfunction, with some of its external components overheating.

(d) Discuss the ways in which the component can and cannot cool down while the satellite remains in orbit.

(3 marks)

5 (a) Scientists modelling climate change are considering the effects of a range of actions on a global scale.

One possible model theorises an Earth with no atmosphere.

(a) Explain why scientists use models which ignore some of the conditions of the situation they are studying. Include the benefits and limitations of this method.

(3 marks)

(b) Energy flow diagrams can be used to represent energy transfers, making them clearer to understand.

(b) Using the data available, draw a diagram showing the energy flows for a 'no-atmosphere' Earth.

Data available:
Incident solar radiation = 350 W m^{-2}
Absorbed solar radiation = 250 W m^{-2}

(3 marks)

(c) The average solar radiation reaching the surface can be found using the following equation:

$$\text{Average intensity at the surface, } I = \frac{(1-\alpha)S}{4}$$

Where α is albedo and S is the solar constant.

(c)

Write an energy balance equation to show that the power received by the Earth is equal to the power radiated by the Earth.

Make clear any assumptions you make.

(3 marks)

(d) (d) The average intensity of radiation reaching the surface is 238 W m^{-2}.

(i) Use the equation determined in part (c) to calculate the surface temperature of the Earth.

[2]

(ii) Comment on the validity of your answer.

[2]

(4 marks)

Hard Questions

1 (a) (a) Suggest how the temperature of a black body can be estimated.

[2]

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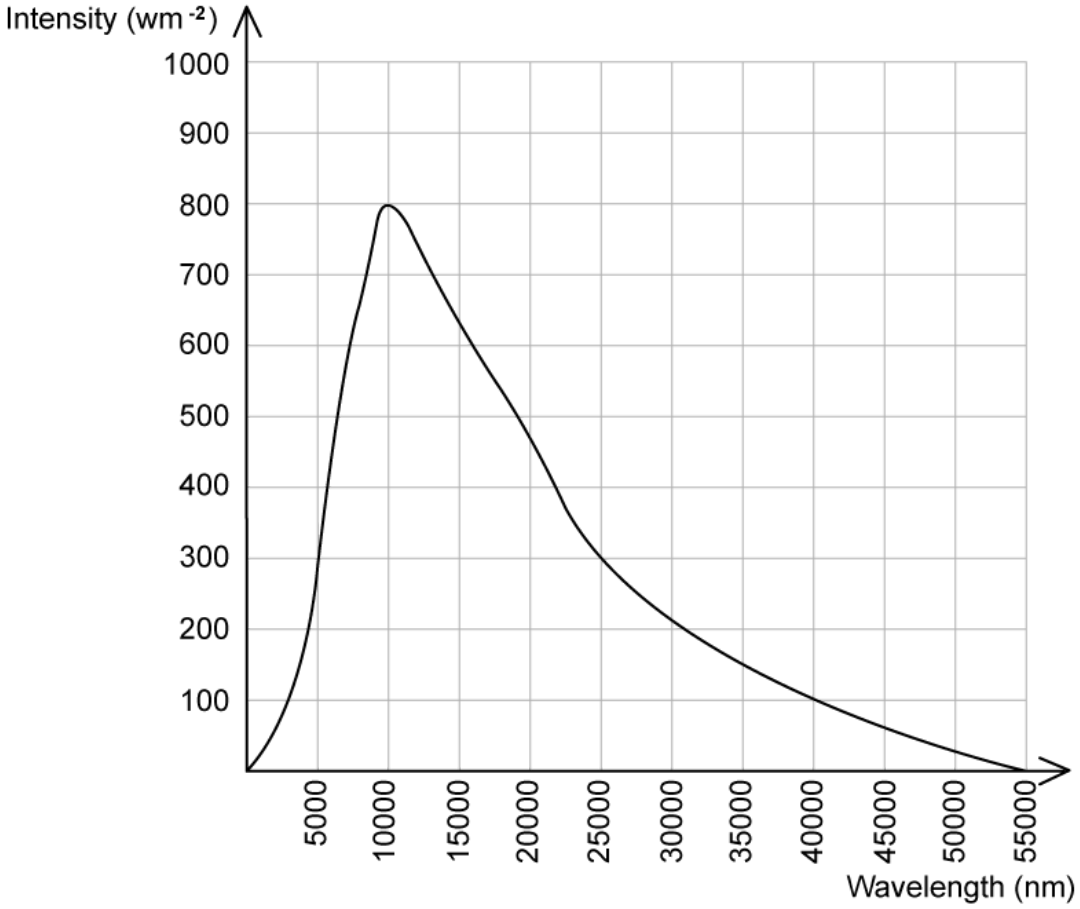
(2 marks)

(b) The spectrum of radiation emitted by a sample of glacier ice is examined.



(b) Calculate the temperature of the radiation emitted by the ice.

[2]

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(2 marks)

(c) (c)

(i) Order fresh snow and ocean ice from lowest to highest in terms of their albedo.

[1]

(ii) Give a reason for your answer.

[1]

(2 marks)

(d) (d) Suggest why the values of the intensity of incident radiation upon the Earth's surface are expected to rise as the climate changes.

[5]

(5 marks)

2 (a) One possible model of climate change is that the Earth will eventually have no atmosphere.

(a)

(i) Draw a suitable diagram to illustrate this model.

[1]

(ii) Evaluate this model.

[2]

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(3 marks)

(b) Obtain an expression for the average intensity of light at the surface of the Earth in terms of albedo and the solar constant.

[4]

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(b) **(4 marks)**

3 (a) A team of engineers are designing solar panels to power a Mars Rover on the surface of Mars.

(a) Derive an expression for the intensity of radiation at a distance, r emitted from a point source.

[2]

(2 marks)

(b) A planned Mars Rover will be powered using several solar panels each with dimensions of 2700 × 4900 mm. The equipment is tested on Earth at a point where the albedo of Earth's atmosphere is 0.390. The following additional information is available:

- The radiant power of the Sun is 3.90×10^{26} W
- The average radius of Earth's orbit around the Sun is 1.50×10^{11} m
- Orbital radius between Mars and the Sun = 2.3×10^{11} m
- Absorbed solar radiation on Mars = 493 W m^{-2}

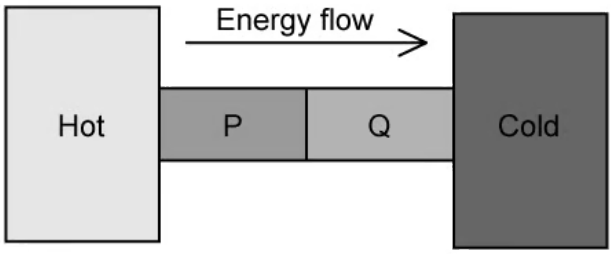
(b) Determine the ratio $\frac{P_M}{P_E}$.

Where P_M is the power of solar radiation incident on the solar panel on Mars and P_E is the power of solar radiation incident on the solar panel on Earth.
Assume that the Sun is at its highest point and the light from the Sun is normally incident on the panel.

[6]

(6 marks)

4 (a) A regular cuboid is made up of two materials, P and Q. The cuboid's dimensions are uniform throughout P and Q. The cylinder is placed in contact with a hot and cold source such that energy is conducted between them.



(a) State and explain whether the following values are equal for the cylinder:

(i) The energy flow rates through P and Q.

[1]

(ii) The temperature difference across P and the temperature difference across Q.

[1]

.....

.....

(2 marks)

(b) The following data are available for two metallic elements.

Silver	**Gold**
Density = 10.49 g cm^{-3}	Density = 19.3 g cm^{-3}
Relative atomic mass = 107.8682	Relative atomic mass = 196.9665

(b)

(i) Determine whether silver or gold is a better conductor of electricity.

[4]

(ii) State the assumption made in the calculation from part (i).

[1]

(5 marks)

(c) (c) Compare and contrast onshore and offshore winds both during the day and at night.

[4]

(4 marks)

(d) A car engine has a malfunction with some of its internal components overheating.

(d) Analyse the ways that the different types of car component can cool down.

[3]

(3 marks)

5 (a) An industrial kiln is used for 'firing' ceramic and pottery items at very high temperatures.

The kiln emits electromagnetic radiation of peak wavelength, $\lambda_{max} = 3.75 \times 10^{-6}$ m and has a surface area of 150 m^2.

(a) Calculate the energy radiated per second.

[4]

(4 marks)

(b) (b) Justify each of the following safety features in the kiln by referring to thermal energy transfer.

(i) The installation of chimneys and vents.

[1]

(ii) Air space created below and around the kiln.

[1]

(iii) Shiny reflective surfaces fixed around the inside of the exterior walls.

[1]

(3 marks)