# 8.5 GREENHOUSE EFFECT
# 8.6 GLOBAL WARMING *HW/Study Packet*

| SL/HL | |
|---|---|
| Required:<br>READ Tsokos, pp 434-450 | Supplemental:<br>8.5 READING - The Greenhouse Effect<br>8.6 READING - Global Warming |
| DO Questions pp 450-453<br>#2,3,4,9,20,23,30 | |

**REMEMBER TO….**

- ✓ *Work through all of the 'example problems' in the texts as you are reading them*
- ✓ *Refer to the **IB Physics Guide** for details on what you need to know about this topic*
- ✓ *Refer to the **Study Guides** for suggested exercises to do each night*
- ✓ *First try to do these problems using only what is provided to you from the **IB Data Booklet***
- ✓ *Refer to the solutions/key ONLY after you have attempted the problems to the best of your ability*

**UNIT OUTLINE**

**I. SOLAR RADIATION**
- A. INTENSITY OF SOLAR RADIATION ON THE EARTH
- B. ALBEDO

**II. THE GREENHOUSE EFFECT**
- A. INTERACTION BETWEEN LIGHT AND MATTER
- B. THE MAIN GREENHOUSE GASES
- C. BLACKBODY RADIATION AND THE STEFAN-BOLTZMANN LAW
- D. ENERGY BALANCE AND CLIMATE MODELS

**III. GLOBAL WARMING**
- A. THE ROLE OF FOSSIL FUELS IN CLIMATE CHANGE
- B. EVIDENCE OF CLIMATE CHANGE
- C. CONSEQUENCES OF CLIMATE CHANGE
- D. SOLVING THE PROBLEM

**FROM THE IB DATA BOOKLET**

$$\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$$

$$\text{power} = \sigma A T^4$$

$$\text{power} = e \sigma A T^4$$

$$\Delta T = \frac{(I_{\text{in}} - I_{\text{out}})\Delta t}{C_s}$$

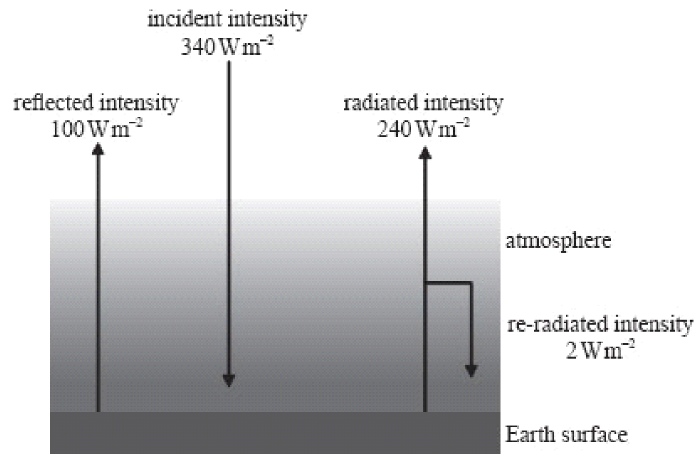
$$C_s = \frac{Q}{A \Delta T}$$

**WHAT YOU SHOULD BE ABLE TO DO AT THE END OF THIS TOPIC**

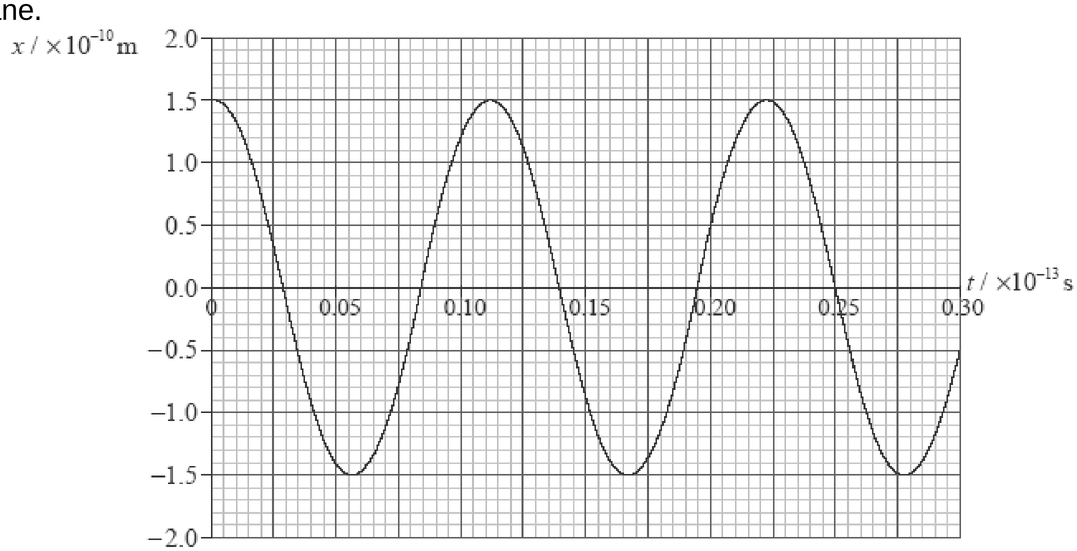
- □ Calculate the intensity of the Sun's radiation incident on a planet.
- □ Define *albedo* and state factors that determine a planet's albedo.
- □ Describe the greenhouse effect and identify the main greenhouse gases and their sources.
- □ Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation.
- □ Analyze absorption graphs to compare the relative effects of different greenhouse gases.
- □ Outline the nature of blackbody radiation and draw and annotate a graph of the emission spectra.
- □ State the Stefan–Boltzmann law and apply it to compare emission rates from different surfaces.
- □ Apply the concept of emissivity to compare the emission rates from different surfaces.
- □ Solve problems on the greenhouse effect and the heating of planets using a simple model.
- □ Describe models of global warming and evidence linking fossil fuels to climate change.
- □ Describe evidence of global warming, consequences of it, and possible solutions.

**HOMEWORK PROBLEMS:**

**1.** The diagram shows a simplified model of the energy balance for Earth. Determine the albedo of the Earth according to this model. **[30%]**




**2.** In a simple model of a methane molecule, a hydrogen atom and the carbon atom can be regarded as two masses attached by a spring. A hydrogen atom is much less massive than the carbon atom such that any displacement of the carbon atom may be ignored. The graph below shows the variation with time *t* of the displacement *x* from its equilibrium position of a hydrogen atom in a molecule of methane.




The mass of hydrogen atom is $1.7 \times 10^{-27}$ kg. Use data from the graph to determine:

a) its amplitude of oscillation. **[$1.5 \times 10^{-10}$ m]**

b) the frequency of its oscillation. **[$9.1 \times 10^{13}$ Hz]**

c) the maximum kinetic energy of the hydrogen atom. **[$6.2 \times 10^{-18}$ J]**

Assuming that the motion of the hydrogen atom is simple harmonic, its frequency of oscillation $f$ is given by the expression

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_p}},$$

where $k$ is the force per unit displacement between a hydrogen atom and the carbon atom and $m_p$ is the mass of a proton.

d) Determine the value of $k$. **[560 N m$^{-1}$]**

e) Estimate the maximum acceleration of the hydrogen atom. **[5.0 x 10$^{19}$ m s$^{-2}$]**

f) Electromagnetic radiation of frequency 9.1 x 10$^{13}$ Hz is in the infrared region of the electromagnetic spectrum. Suggest, based on your answer to part (b), why methane is classified as a 'greenhouse gas'.

**3.** A copper ball 2.0 cm in radius is heated in a furnace to 4.0 x 10$^{2}$ C. If its emissivity is 0.30, at what rate does it radiate energy? **[1.7 Js$^{-1}$]**

**4.** The sun radiates energy at the rate of 6.5 x 10$^{7}$ Wm$^{2}$ from its surface. Assuming that the sun radiates as a blackbody, find its surface temperature. **[5800 K]**

**5.** The following data relate to the Earth and the Sun:

| | |
|---|---|
| *Earth-Sun distance* | *= $1.5 \times 10^{11}$ m* |
| *radius of Earth* | *= $6.4 \times 10^{6}$ m* |
| *radius of Sun* | *= $7.0 \times 10^{8}$ m* |
| *surface temperature of Sun* | *= 5800 K* |

a) Using data from the table, calculate the power radiated by the Sun. **[$4.0 \times 10^{26}$ W]**

b) Calculate the solar power incident per unit area at a distance from the Sun equal to the Earth's distance from the Sun. **[1400 $Wm^{-2}$]**

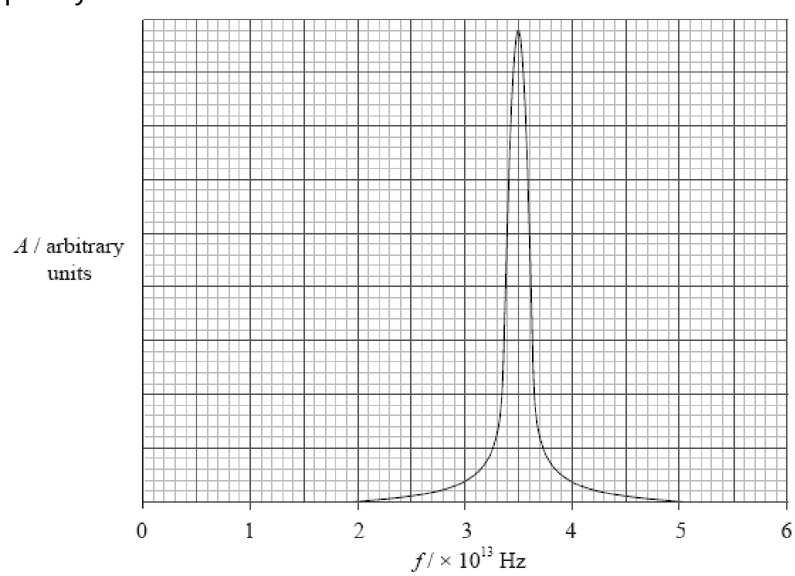
c) Show that the value for power absorbed per unit area of 240 W $m^{-2}$ (for the Earth) is consistent with an average equilibrium temperature for Earth of about 255 K.

d) Explain, by reference to the greenhouse effect, why the average temperature of the surface of the Earth is greater than 255 K.

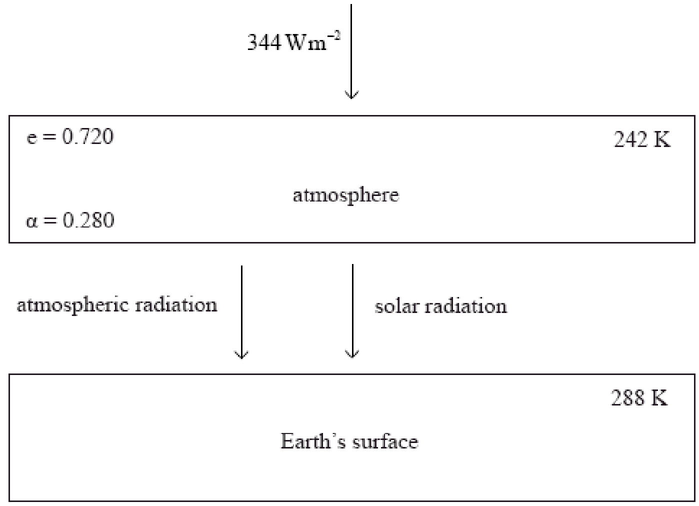
**6.** The graph shows part of the absorption spectrum of nitrogen oxide ($N_2O$) in which the intensity of absorbed radiation *A* is plotted against frequency *f*.

a) State the region of the electromagnetic spectrum to which the resonant frequency of nitrogen oxide belongs. **[infrared]**

b) Using your answer to (a), explain why nitrogen oxide is classified as a greenhouse gas.



c) The diagram shows a simple energy balance climate model in which the atmosphere and the surface of Earth are two bodies each at constant temperature. The surface of the Earth receives both solar radiation and radiation emitted from the atmosphere. Assume that the Earth's surface behaves as a black body.




The following data are available for this model:

*average temperature of the atmosphere of Earth* = *242 K*
*emissivity, e of the atmosphere of Earth* = *0.720*
*average albedo, α of the atmosphere of Earth* = *0.280*
*solar intensity at top of atmosphere* = *344 W* $m^{-2}$
*average temperature of the surface of Earth* = *288 K*

Determine:

d) The power radiated per unit area of the atmosphere. **[140 W $m^{-2}$]**

e) The solar power absorbed per unit area at the surface of the Earth. **[248 W $m^{-2}$]**

It is hypothesized that, if the production of greenhouse gases were to stay at its present level then the temperature of the Earth's atmosphere would eventually rise by 6.0 K.

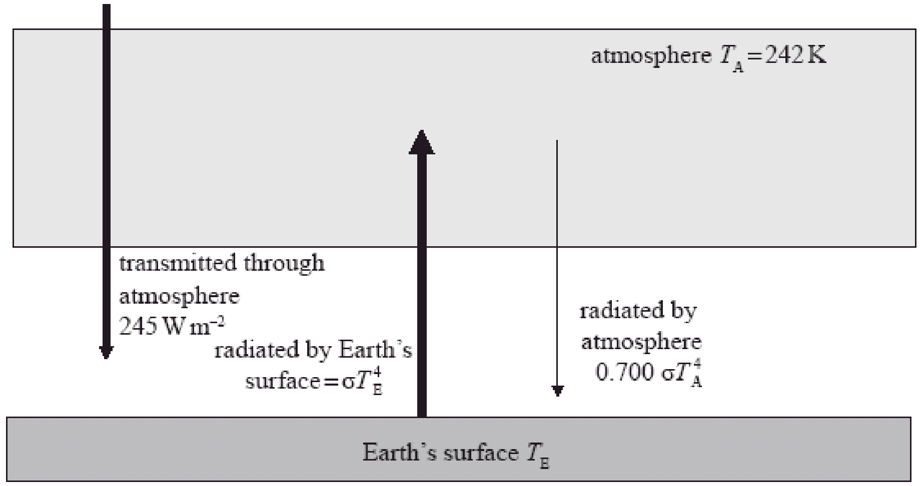
f) Calculate the power per unit area that would then be radiated by the atmosphere. **[154 W$m^{-2}$]**

g) Calculate the power per unit area that would then be absorbed by the Earth's surface. **[402 W$m^{-2}$]**

h) Estimate the increase in temperature of Earth's surface. **[2 K]**

**7.** The diagram shows a simplified model of the energy balance of the Earth's surface. The diagram shows radiation entering or leaving the Earth's surface only.

The average equilibrium temperature of the Earth's surface is $T_E$ and that of the atmosphere is $T_A$ = 242 K.




a) Using the data from the diagram, state the emissivity of the atmosphere. **[0.7]**

b) Determine the intensity of the radiation radiated by the atmosphere towards the Earth's surface. **[136 W m$^{-2}$]**

c) Calculate $T_E$. **[286 K]**

**8.** One effect of global warming is to melt the Antarctic ice sheet. The following data are available for the Antarctic ice sheet and the Earth's oceans.

| | |
|---|---|
| *Area of ice sheet* | *= 1.4 × $10^7$ km$^2$* |
| *Average thickness of ice* | *= 1.5 × $10^3$ m* |
| *Density of ice* | *= 920 kg m$^{-3}$* |
| *Density of water* | *= 1000 kg m$^{-3}$* |
| *Area of Earth's oceans* | *= 3.8 × $10^8$ km$^2$* |

Using the data, determine:

a) the mass of the Antarctic ice. **[1.9 x $10^{19}$ kg]**

b) the change in mean sea level if all the Antarctic ice sheet were to melt and flow into the oceans. **[50 m]**