Problem of the week

The greenhouse effect

(a) State what you understand by the term *solar constant*.

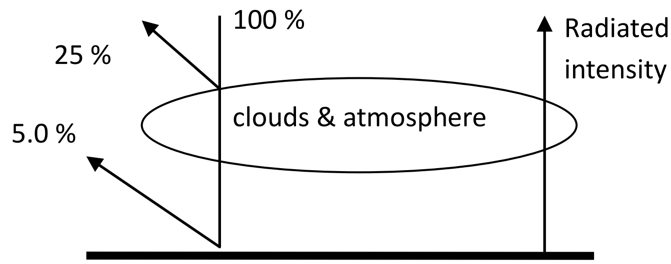
(b) The solar constant is S. Explain the average intensity on the entire earth surface is $\frac{S}{4}$.

(c)

(i) Define albedo.

(ii) State two factors that albedo depends on.

(d) The diagram shows a simple energy balance for a planet ignoring the greenhouse effect.

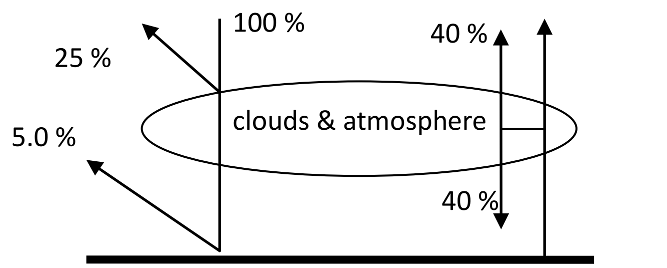


(i) Calculate the albedo of the planet.

(ii) Determine the percentage intensity radiated by the planet into space.

(iii) Assuming the surface behaves as a black body, determine the equilibrium temperature of the surface given that the incident intensity is 340 W m^{-2}.

(e) The diagram shows the energy balance for the planet in (d) taking the greenhouse effect into account.



Assuming surface behaves as a black body, determine the equilibrium temperature of the surface given that the incident intensity is 340 W m^{-2}.

(f)

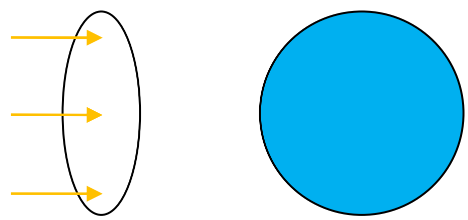
(i) Describe the mechanism by which greenhouse gases absorb part of the radiation emitted by the surface.

(ii) Suggest why the greenhouse gases do not absorb any appreciable amount of the radiation incident from the Sun.

Answers

(a) The intensity of the Sun's radiation at the upper atmosphere of earth.

(b) Radiation reaching the earth from the Sun must go through a circle of radius equal to that of earth.



The power through this circle is $P = SA = S\pi R^2$. This power is distributed over the entire earth surface area and so the average intensity is $I_{\text{average}} = \frac{P}{4\pi R^2} = \frac{S\pi R^2}{4\pi R^2} = \frac{S}{4}$.

(c)

(i) The ratio of reflected intensity to incident intensity.

(ii) Cloud cover, type of vegetation, moisture, nature of surface (ice/desert/forest/urban environment etc.)

(d)

(i) 30% of the incident intensity is reflected so the albedo is 0.30.

(ii) To have an energy balance, 70% of the incident intensity is radiated.

(iii) The radiated intensity is $I = 0.70 \times 340 = 2.38 \times 10^2 \approx 2.4 \times 10^2 \text{ W m}^{-2}$. Hence,

$$\sigma T^4 = 2.38 \times 10^2 \Rightarrow T = \sqrt[4]{\frac{2.38 \times 10^2}{5.67 \times 10^{-8}}} = 254 \approx 250 \text{ K}.$$

(e) The radiated intensity is now $I = 1.10 \times 340 = 3.74 \times 10^2 \text{ W m}^{-2}$. Hence,

$$\sigma T^4 = 3.74 \times 10^2 \Rightarrow T = \sqrt[4]{\frac{3.74 \times 10^2}{5.67 \times 10^{-8}}} = 285 \approx 280 \text{ K}.$$

(f)

(i) The photons of the radiation emitted by the surface are infrared photons. The greenhouse gases have molecular energy levels whose energy differences correspond to infrared photons frequencies. Hence these photons are absorbed (and then re-radiated in all directions).

(ii) Very few of the incident photons are infrared photons. Most are ultraviolet and visible photons whose energies are larger than the energy level differences of the gases so they cannot be absorbed.