GREENHOUSE EFFECT

AN INTRODUCTION TO THERMAL RADIATION

PREAMBLE

The original form of the problem is the first part of a four week (15 credit) module in the IScience programme at the University of Leicester providing an introduction to thermal and atmospheric physics.

MODULE PACING

The problem is run over one week with the following **pattern:**

Facilitated workshop – problems for class discussion (2 hours)

Lecture

Facilitated workshop – problems for class discussion (1 hour)

Lecture

Tutorial on individual exercises

INTENDED LEARNING OUTCOMES

By the end of the module students should be able to:

- Use basic knowledge of Thermodynamics (the physics of energy); latent heat (phase change) and 'sensible heat' (raising temperature within a phase).
- State the major regions of the electromagnetic spectrum and their approximate wavelengths.
- Discuss the interaction of radiation with matter: absorption, reflection, transmission, scattering and define black body radiation.
- Describe the Sun's radiation; the spectrum at the top of Earth's atmosphere.
- Calculate radiation at the Earth's surface; outgoing radiation.
- State and use the Stefan-Boltzmann law to calculate the power radiated by a body at a given temperature; calculate the equilibrium temperature of a body absorbing a given power of radiation.
- State and use Wien's Law to calculate the peak wavelength of radiation of a given body at a given temperature.

READING LIST

The reading list is that provided for the original module. Other equivalent textbooks are available.

READY TO STUDY

- Breithhaupt, J., ***Physics***. Palgrave Foundations.
- Trefil, J. & Hazen, R. M., ***Sciences: An Integrated Approach***. Wiley.

ESSENTIAL

- Knight, R.D., Jones, B. & Field, S. ***College Physics: A Strategic Approach***, Pearson International.

PROBLEM STATEMENT

Leaving dogs in parked cars can be deadly

By Stephanie Gaj - Special Correspondent July 5, 2003

NORWALK -- Leaving dogs alone in parked cars during hot summer months, even with the windows partially rolled down, can put the animals in danger.

"People think if they park in the shade or leave windows open a bit the animal will cope, but when they go back to their cars the first thing you see people do is turn on the (air conditioner) or roll down the windows. They know it's too hot for them," said Priscilla Feral, president of Friends of Animals in Darien.

Because of the greenhouse effect, sunny days can be deadly for dogs, even in moderately warm temperatures. The temperature inside the car is much higher than the temperature outside because the car traps the heated air.

"Cars can heat up to dangerous temperatures within a few minutes," said Alicia Wright, director of volunteer services at the Connecticut Humane Society.

When a dog's temperature reaches above 105 or 106 degrees for five or 10 minutes, it puts the dog at risk and can cause cell death, said Chapnick.

Friends of Animals was responsible for signs in the parking lot at The Maritime Aquarium at Norwalk warning people not to leave dogs unattended in cars.

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SUGGESTED DELIVERABLES

Computer program or Excel spreadsheet

Short report

QUESTIONS FOR CLASS DISCUSSION

With increasing concentrations of greenhouse gases in the Earth's atmosphere, the global mean surface and near surface temperatures are expected to rise. The problems presented in the facilitation sessions will allow you to recognize and analyze how temperatures are determined by radiation, adjusted through the presence of greenhouse gases.

1. Find a value for:

- The radius of the Earth
- The solar constant
- The mean global shortwave albedo
- The mean global temperature

2. Calculate the mean incident solar radiation per m^2 on Earth. Questions you may like to consider in order to calculate this value:

- What assumptions do you need to make in order to construct a model?
- What is the "solar constant" (definition and numerical value)?
- What are the time and space domains you have to average over, i.e. how is the radiation distributed over the surface of the earth?
- How do these calculations relate to Problem Statement ?

3. How long would it take for the outer 4 km of the Earth's surface (i.e. ocean and continents) to warm by 1 K if the Earth only retained 1% of the incoming radiation per m2. Again, consider how this task may be relevant to your answer to Problem Statement 01.

4. Determine the surface temperature of the Earth if it had an albedo of a) 0 and b) a realistic value. Assume that the Earth retains any energy that it does not reflect. For this activity assume that the atmosphere is completely transparent, i.e. it has no effect on the transmission of the incident radiation.

Questions to consider:

- What is albedo? What does an albedo of 0 represent? Why is this not realistic?
- What value of albedo will you use in part b)? If you choose to use an average value why did you choose it and how did you calculate it?
- Do you think that the final answers from your calculations (using the assumptions stated above) are reasonable?
- How do these calculations relate to the Problem Statement?

5. Up until now the effect of the atmosphere in your model has been ignored. In reality the atmosphere is not completely transparent to radiation. The atmosphere absorbs radiation, mainly long wave radiation, due to the greenhouse gases in the atmosphere.

- How would you modify the calculations from question 4 to take this into account?
- How does the newly calculated temperature of the Earth system compare to the real global mean temperature?
- Does this have any impact on your car heating model?

INDIVIDUAL EXERCISES

a) Find the density of moist air with specific humidity $15\ gkg^{-1}$ (grams of water vapour per kilogram of air), temperature $15°C$ and pressure $1010\ mbar$. The Gas Constant of dry air is $287\ Jkg^{-1}K^{-1}$ and the Gas Constant of water vapour is $462\ Jkg^{-1}K^{-1}$.

b) Compare your result with the density of dry air at the same temperature and pressure.

c) What is the temperature at which a sample of dry air would have the same density as a sample of moist air, assuming both samples are maintained at the same overall pressure? *Note that this last temperature is known as the "Virtual Temperature" of moist air. This value can be used to predict the buoyancy of cloud formations.*

2. The heat capacity of the Arctic Ocean limits the change in temperature of the region during the course of the year. Describe how this effect changes with the freezing and melting of the arctic sea ice at different times of year.

3. a) Briefly describe the processes of Conduction and Convection.

   b) What is the critical difference between the two and how does this lead to a difference in heat transfer in different states of matter?

4. a) Assuming a constant value of g and a constant density of $1.2\ kgm^{-3}$, calculate the height of the Earth's atmosphere given that average atmospheric pressure is $101\ kPa$ at sea level.

   b) Compare your result with the actual atmospheric height of $100\ km$. What does this tell you about the density of the atmosphere?

5. Explain mathematically why the pressure of a gas falls if:

   a) its volume is increased at a constant mass and temperature.
   b) its temperature is reduced at constant mass and volume.
   c) By calculating the relative r.m.s. speeds of Hydrogen and Oxygen molecules, explain why the Earth's Atmosphere retains Oxygen but not Hydrogen. You may take the molar mass of Hydrogen to be $0.002\ kg$ and the molar mass of Oxygen to be $0.032\ kg$.

6. The solar power received at the top of the atmosphere can be described by the relation:

$$S \propto \frac{1}{D^2}$$

   where S is the received Solar Power and D is the distance between the Earth and the Sun.

   For mean solar distance (D_{Avg} = 149.5x10^6 km) the power flux at the top of the atmosphere can be taken as $1.35\ kWm^{-2}$. Using this information, calculate the power received at the top of the atmosphere when:

   a) the Earth is at perihelion (D = 152x10^{6}km). [5]
   b) the Earth is at aphelion (D = 147x10^{6}km).

7. A black-and-white cat is lying in strong sunlight. Describe and explain its appearance when viewed by a radiometer sensitive to the far infra-red whose display renders strong radiators white and weak radiators black.

8. Estimate how much energy is required to raise the average temperature by 1^{o}C, of;

   a) the atmosphere

   b) the oceans

9. Determine the blackbody radiation (in Wm^{-2}) emitted from an object with a temperature of:

   a) 6000K
   b) 300K

You may take the Stefan-Boltzmann constant to be σ = 5.67x10^{-8} Wm^{-2}K^{-4}.

10. Using Stefan-Boltzmann's Law, show that the effective temperature of the Earth is approximately 255 K. The Earth emits radiation at a flux of approximately 240 Wm^{-2}.

11. Starting with the shortest, place the following spectral ranges in the correct order of wavelength: Visible, X-ray, Ultraviolet, Microwave, Infra-Red.

12. a) Assuming that the peak-intensity wavelength of light emitted from the sun is *500 nm*, use Wien's law to achieve an estimate for the sun's surface temperature.

    b) Given that the intensity of solar radiation at the Earth is 1.4 kWm^{-2} and that the Earth orbits at a distance of 1.5 x 10^{11} m from the sun, calculate an estimate for the energy radiated by the sun every second.

    c) Hence estimate the emissivity of the sun, assuming the sun to be a perfectly spherical emitter with a diameter of 1.4x10^{9} m.

The Stefan-Boltzmann constant is given as σ = 5.67x10^{-8} Wm^{-2}K^{-4}.