IB Physics Lesson Year Two:
Standards from IB Subject Guide beginning 2016

Planet Designer: Kelvin Climber
IB Physics Standards taken from Topic 8: Energy Production

8.2 – Thermal energy transfer

Nature of science:
Simple and complex modelling: The kinetic theory of gases is a simple mathematical model that produces a good approximation of the behaviour of real gases. Scientists are also attempting to model the Earth's climate, which is a far more complex system. Advances in data availability and the ability to include more processes in the models together with continued testing and scientific debate on the various models will improve the ability to predict climate change more accurately. (1.12)

Understandings:

- Conduction, convection and thermal radiation
- Black-body radiation
- Albedo and emissivity
- The solar constant
- The greenhouse effect
- Energy balance in the Earth surface–atmosphere system

Applications and skills:

- Sketching and interpreting graphs showing the variation of intensity with wavelength for bodies emitting thermal radiation at different temperatures
- Solving problems involving the Stefan–Boltzmann law and Wien's displacement law
- Describing the effects of the Earth's atmosphere on the mean surface temperature
- Solving problems involving albedo, emissivity, solar constant and the Earth's average temperature

Guidance:

- Discussion of conduction and convection will be qualitative only
- Discussion of conduction is limited to intermolecular and electron collisions
- Discussion of convection is limited to simple gas or liquid transfer via density differences
- The absorption of infrared radiation by greenhouse gases should be described in terms of the molecular energy levels and the subsequent emission of radiation in all directions
- The greenhouse gases to be considered are CH_4, H_2O, $CO_2$and N_2O. It is sufficient for students to know that each has both natural and man-made origins.

- Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. The global annual mean albedo will be taken to be 0.3 (30%) for Earth.

Data booklet reference:

- $P = e\sigma AT^4$
- $\lambda_{max}(\text{metres}) = 2.90 \times 10^{-3} T(\text{kelvin})$
- $I = \text{power}/A$
- albedo = total scattered power/total incident power

International-mindedness:

- The concern over the possible impact of climate change has resulted in an abundance of international press coverage, many political discussions within and between nations, and the consideration of people, corporations, and the environment when deciding on future plans for our planet. IB graduates should be aware of the science behind many of these scenarios.

Theory of knowledge:

- The debate about global warming illustrates the difficulties that arise when scientists cannot always agree on the interpretation of the data, especially as the solution would involve large-scale action through international government cooperation. When scientists disagree, how do we decide between competing theories?

Utilization:

- Climate models and the variation in detail/processes included
- Environmental chemistry (see *Chemistry* option topic *C*)
- Climate change (see *Biology* sub-topic *4.4* and *Environmental systems and societies* topics *5* and *6*)
- The normal distribution curve is explored in *Mathematical studies SL* sub-topic *4.1*

Aims:

- **Aim 4:** this topic gives students the opportunity to understand the wide range of scientific analysis behind climate change issues
- **Aim 6:** simulations of energy exchange in the Earth surface–atmosphere system
- **Aim 8:** while science has the ability to analyse and possibly help solve climate change issues, students should be aware of the impact of science on the initiation of conditions that allowed climate change due to human contributions to occur. Students should also be aware of the way science can be used to promote the interests of one side of the debate on climate change (or, conversely, to hinder debate).

Planet Designer: Kelvin Climb

Objective: to determine the planetary conditions necessary for liquid water to exist on the surface of a planet.

Task: Students will use the computer interactive to explore the blackbody temperature of a planet and then determine how greenhouse gases affect the surface temperature and lastly determine how temperature of a blackbody relates to the specific form of EM radiation emitted.

What is the MAVEN mission and why would NASA care if a planet has necessary conditions for liquid water?
Introduction / Motivation:

The MAVEN mission, launching in 2013, will explore the upper atmosphere of Mars. There is quite a bit of evidence that liquid water flowed on the surface of Mars in the past. MAVEN will collect data to help scientists trace Mars' atmospheric history to determine what happened to the flowing water. Today, you will be exploring some of the same principles scientists use to determine how likely it is for a planet to maintain flowing water.
Why do we care about water? Every known life form on Earth requires water to survive, and wherever we find water on Earth, we tend to find life. Finding liquid water on another planet is exciting, not because it means life does exist, but that it could exist. It's that possibility that motivates missions like MAVEN to keep searching for clues about Mars' early history.
Today, you are going to explore the basics of planetary temperature. You'll start by creating your own planet without an atmosphere or surface features on the computer. To calculate planetary temperature, the computer uses a blackbody temperature estimate. A blackbody is a surface that perfectly absorbs and emits all parts of the electromagnetic spectrum equally. Once you add surface features to your planet, it will reflect some of the sunlight (electromagnetic radiation) that hits it and absorb the rest. The albedo of a planet tells us what percentage of sunlight it reflects. For example, a planet with an albedo of 0.5 (or 50%) reflects half the electromagnetic radiation that hits it and absorbs the other half. An albedo of one reflects 100% of the electromagnetic radiation, and an albedo of zero reflects 0% (absorbs everything). The absorbed light heats the surface of the planet, and the planet radiates infrared light (heat) back into space.
A planet might also have an atmosphere that absorbs and emits over parts of the electromagnetic spectrum. When we look at a spectrum of light reflected from an atmosphere, we see dips (absorption) and peaks (emission) from different atoms and molecules. Greenhouse gases in an atmosphere allow visible light to pass through, but absorb infrared light. Visible light from the Sun heats the surface. The heated surface radiates infrared light (heat) out. The greenhouse gases in the atmosphere absorb and reemit some of the infrared light radiated from the surface. Some of it is emitted to space, but some emits toward the surface of the planet, heating it up more. You will add a greenhouse atmosphere to your planet to try to increase the temperature.
Part of your challenge today is to figure out what planetary conditions are necessary for liquid water to exist on the surface of a planet.

Procedure:
Open the computer interactive "Planet Designer: Kelvin Climb."

http://lasp.colorado.edu/home/education/k-12/project-spectra/

Play around with the simulation and complete the handout provided by LASP:
http://lasp.colorado.edu/home/wp-content/uploads/2013/06/KelvinClimb_student_20130617.pdf

In addition to completing the hand-out, define the vocabulary terms below as you go through the simulation.
Albedo
Blackbody
Kelvin
Luminosity
Planetary Surface Temperature
Astronomical Unit (AU)

Greater Depth of Knowledge Questions:
A perfect blackbody will absorb light and radiate with perfect efficiency. When visible light shines on a planet, the planet heats up and radiates increasing amounts of energy in the infrared spectrum.

1. How much energy does the sun produce?
2. Energy travels out from the sun in a sphere and follows the inverse square law:
   $I = P/4\pi r^2$
   a. Draw a picture showing, mathematically, how light spreads from out from a source
   b. Compare the amount of light received by a planet at a location of 2 AU compared to a planet at a location of 1AU

(Problems to be solved in this section using given equations)

3. Intensity of Energy distributed over a surface.
   $I = P/4\pi r^2$ (area over which energy flow is distributed)

4. Luminosity or Power Output of Sun from every square meter (given blackbody temperature of sun)
   $P = \alpha 4\pi r^2 T_s^4$ (T= surface temperature, r=radius of sun, α= Stefan-Boltzmann constant , $\alpha = 5.7 \times 10^{-8} W/m^2K^4$)

Conservation of Energy: Energy in = Energy out
Therefore the amount of energy from the sun that reaches a planet equals the amount of energy emitted by a planet.

5. $(P/(4\pi D^2))\pi r^2(1-\alpha) = 4\pi r^2 \alpha T_b^4$
   P = power output of sun (Luminosity)
   D= distance from sun to planet
   r= area of circle of planet that receives sunlight
   (1- α)= subtract the amount of light reflected off planet
   r= radius of planet
   T_b= blackbody temp of planet

6. Combining equations to determine blackbody temperature of planet:

$T_b = T_s(1-\alpha)^{1/4}\sqrt{(R/2D)}$ T_b= blackbody temperature of planet
Ts = blackbody temperature of sun

α=albedo of planet
R= radius of sun
D= Distance from sun to planet

Note: The equation does not account for greenhouse gases effect on temperature of a planet's surface. Therefore in the simulation a correction factor (N) was used to simulate greenhouse strength.

Power emitted through blackbody radiation = Actual Power emitted by planet

$\alpha T^4 = N\ \alpha T_a^4$

Simulation Questions:

1. What were the necessary conditions in order for a planet to support liquid water?
2. Describe the limitations of the Kelvin Climb simulation.
3. What factors on earth affect the earth's albedo? Explain whether each factor increases or decrease the earth's albedo.
4. How would a changing albedo cause a change in the planetary surface temperature?
5. How does the temperature of your planet relate to the EM radiation emitted by the planet? (Could lead into the Remote Sensing of Ice on Mars activity)