Astrophysics

IB Physics Content Guide

Big Ideas

- Radiation intensity is related to separation distance by the inverse square law (similar to force fields)
- The Earth's climate relies on a delicate thermal energy balance where total energy in equals total energy out
- A variety of measurements from earth can be used to calculate the distance of stars and galaxies
- The scale of our universe is so vast that we need to define new units to help conceptualize its overall size
- It is possible to measure the emission or absorption spectrum of a star to determine its composition
- The properties of stars can be organized into a chart and used to predict the future life cycles

1 – Radiation from Stars

I can define and compare the properties of luminosity and brightness			
I can calculate luminosity using Stefan-Boltzmann's Law			
I can calculate the surface area of a sphere			
I can describe and calculate how the brightness changes based on the distance from a source			
I can determine the temperature of a hot object based on the peak wavelength emitted			
I can use brightness, peak wavelength, and distance to calculate temperature, luminosity, and radius for a star			

2 – Radiation from the Sun

I can define intensity with proper units			
I can describe how intensity changes according to the surface area of a sphere			
I can derive the Solar Constant from the sun's power and distance from earth			
I can calculate the average solar intensity on earth from the solar constant and earth's radius			
I can compare the properties of albedo and emissivity			

3 – Climate Change

I can describe the greenhouse effect as absorption and re-emission of thermal energy			
I can list the gases that have the largest impact on the greenhouse effect and their natural/human sources			
I can describe the long term and seasonal trends in the carbon dioxide concentration			
I can list examples of positive and negative feedback loops in terms of the climate discussion			

4 – Organizing the Stars

I can place a star on an axis showing luminosity vs temperature			
I can describe the organization of the Hertzsprung-Russell Diagram			
I can use the main sequence to calculate the distance of a star from its wavelength and brightness			
I can identify the chemical makeup of a star from its absorption spectrum			

5 – Measuring Astronomical Distances

I can convert between lightyears, parsecs, and astronomical units			
I can determine distance for nearby stars using the parallax method			
I can determine distance for main sequence stars using temperature and brightness			
I can convert between lightyears, parsecs, and astronomical units			
I can determine distance for nearby stars using the parallax method			

6 – Stellar Evolution

I can describe the process of fusion and conditions required for it to happen			
I can calculate the energy released in a fusion reaction			
I can discuss the forces involved in stellar equilibrium			
I can describe the life cycle of a star			
I can describe the differences in fusion for an average and massive star			
I can predict the death outcome of a star based on the mass of its core at the end of life			

7 – Redshift

I can describe how light changes when the source is moving			
I can use a shift in wavelength or frequency to calculate the speed of the wave source			

Stellar Quantities

Luminosity	Brightness
How much total power a star emits Units: W	Star intensity to an observer on earth Units: W m^{-2}

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

$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$

Variable Symbol	Description	Unit
L	Luminosity	[W]
σ	Stephan-Boltzmann Constant	[W m^{-2} K^{-4}]
A	Surface Area ($A_{sphere} = 4\pi r^2$)	[m^2]
T	Temperature	[T]

$$b = \frac{L}{4\pi d^2}$$

Variable Symbol	Description	Unit
b	Brightness	[W/m^2] or [W m^{-2}]
L	Luminosity	[W]
d	Distance from Light Source	[m]

$$\lambda_{\max} T = 2.9 \times 10^{-3}\ \mathrm{m\,K}$$

Variable Symbol	Description	Unit
λ_{max}	Maximum Wavelength	[m]
T	Temperature	[K]

Average Solar Intensity

Sun's Power = 3.84×10^{26} W	Earth's Distance from Sun = 1.5×10^{11} m	Earth's Radius = 6.37×10^{6} m

Solar Intensity at the Earth's Orbit

$$b = \frac{L}{4\pi d^2} = \frac{3.84 \times 10^{26}}{4\pi (1.5 \times 10^{11})^2} = \mathbf{1358\ Wm^{-2}}$$

Average Solar Intensity on Earth's Surface

$$1358\ \mathrm{Wm^{-2}} \times \frac{\pi (6.37 \times 10^{6})^2}{4\pi (6.37 \times 10^{6})^2} = \mathbf{340\ Wm^{-2}}$$

Average Solar Intensity on Earth's Surface (**shortcut**)

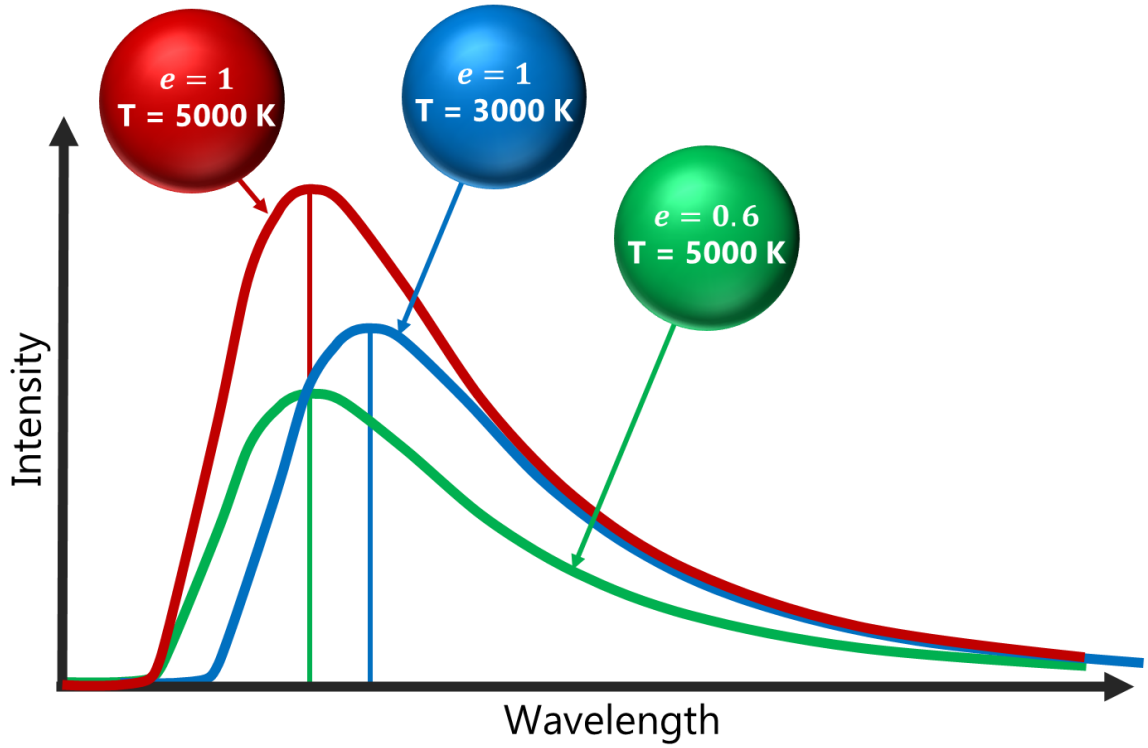
$$\frac{1358\ \mathrm{Wm^{-2}}}{4} = \mathbf{340\ Wm^{-2}}$$

Emissivity and Albedo

	Equation	Definition	Black Body	Shiny Body
Emissivity	$\frac{power\ radiated\ per\ unit\ area}{\sigma T^4}$	% Absorbed	1	0
Albedo	$\frac{total\ scattered\ power}{total\ incident\ power}$	% Emitted	0	1

Blackbody Radiation

Sketch in the radiation curves for the other two objects shown



Climate Change

Positive Feedback Loop	Negative Feedback Loop
Melting ice (decreases albedo)	Cloud formation (increases albedo)
Melting permafrost (releases methane)	Increased photosynthesis (decreases the amount of CO_2 in the atmosphere)
Rising ocean temp (releases methane)	Climate Change leads to society change and more renewable energy sources

Sources of Greenhouse Gases

Greenhouse Gas	Natural	Human Activity
Water Vapor	• Water Cycle	• Hotter planet evaporates more water
Carbon Dioxide	• Carbon Cycle	• Fossil Fuel Combustion
Oxygen/Ozone	• Reaction in the presence of sunlight	• Emissions
Methane	• Termites • Melting Permafrost	• Leaks from natural gas • Raising of Livestock
Nitrous Oxide	• Nitrogen Cycle	• Agriculture • Wastewater Management

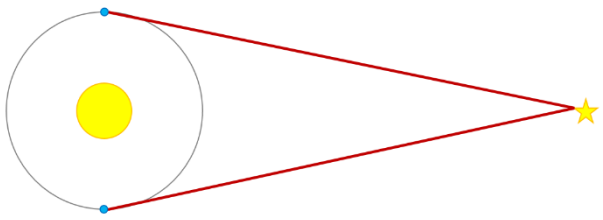
Astronomical Distances

Unit Conversion	Definition
1 light year (ly) = **9.46×10^{15} m**	The distance the light travels in an earth year
1 parsec (pc) = **3.26 ly**	The distance at which the mean radius of the earth's orbit subtends an angle of 1 arc second
1 astronomical unit (AU) = **1.50×10^{11} m**	The average distance between the earth and the sun

$$d\ (\text{parsec}) = \frac{1}{p\ (\text{arc} - \text{second})}$$

Variable Symbol	Description	Unit
d	Distance	Parsecs [pc]
p	Parallax Angle	Arc-seconds [as]

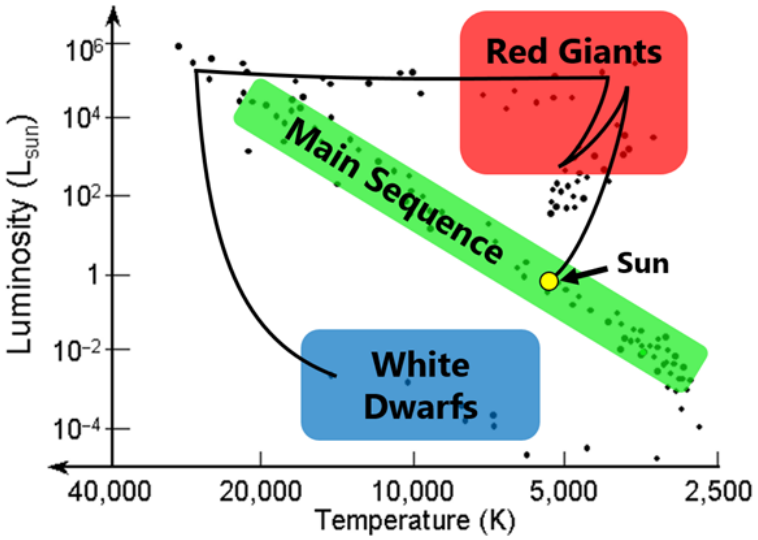
Describe the process of Stellar Parallax:
Observe how far a star moves relative to distant stars six months apart so that earth has its maximum displacement and an angle can be measured



H-R Diagrams and Life Cycle of a Star

Label the Following:

- ☐ Main Sequence
- ☐ White Dwarfs
- ☐ Red Giants
- ☐ The Sun
- ☐ Line representing the life cycle of our sun



Death Outcomes

Sun Like Stars (< 1.5 $M_\odot$)	Huge Stars (1.5 – 3 $M_\odot$)	Giant Stars (> 3 $M_\odot$)
⬇	⬇	⬇
White Dwarf	Neutron Star	Black Hole

Doppler Effect

$$\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$$

$$c = 3.00 \times 10^8 \frac{m}{s}$$

Variable Symbol	Description	Unit
Δf	Change in Frequency	[Hz]
f	Frequency	[Hz]
$\Delta \lambda$	Change in Wavelength	[m] or [nm]
λ	Wavelength	[m] or [nm]
v	Speed of Source	[m/s]
c	Speed of Light	[m/s]

Redshift	Light source is moving **away from** the observer
Blueshift	Light source is moving **toward** the observer