TOPIC 1 Luminosity of a Star

SQ 21.1.1 Define luminosity of a star.

Definition

Luminosity is the total amount of energy emitted by a star per unit time in the form of electromagnetic radiations.

SQ 21.1.2 Write the symbol and unit of luminosity.

Answer

Luminosity is represented by the symbol L and is measured in watts, indicating the total power of radiation emitted by a star.

SQ 21.1.3 On what does the luminosity of a star primarily depend?

Answer

Luminosity primarily depends on the radius and the surface temperature of the star.

SQ 21.1.4 Why are larger stars more luminous?

Reason

Larger stars have more surface area to emit radiations, and therefore tend to be more luminous.

SQ 21.1.5 For stars of equal size, which one is more luminous?

Answer

For stars of equal size, the one with the higher surface temperature will radiate more energy and hence exhibit greater luminosity.

SQ 21.1.6 State the Stefan-Boltzmann law.

Statement

The total output power of a star is directly proportional to the product of its surface area and the fourth power of its temperature.

Formula

$$L = 4\pi r^2 \sigma T^4$$

SQ 21.1.7 Write the value of the Stefan-Boltzmann constant.

Value

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

SQ 21.1.8 What is the luminosity of the Sun?

Answer

The Sun shines with an immense luminosity of about $4 \times 10^{26}\,\mathrm{W}$, which is equivalent to billions of nuclear explosions happening every second.

SQ 21.1.9 How does the Stefan-Boltzmann law help astronomers?

Answer

Stefan-Boltzmann's law helps astronomers estimate the size and brightness of stars, just by knowing their temperature.

SQ 21.1.10 A star has L = 2.5 × 10^{26} W and T = 6000 K. Estimate its radius.

Solution

Using

$$r = \sqrt{\frac{L}{4\pi\sigma T^4}}$$

Calculation

$$r = \sqrt{\frac{2.5 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times (6000)^4}}$$

Result

$$r = 5.2 \times 10^{8}\,\mathrm{m}$$

SQ 21.1.11 If a star becomes twice as hot, how many times more energy will it radiate?

Answer

Since $L \propto T^4$, doubling the temperature increases the radiated energy by a factor of

$$2^4 = 16$$

TOPIC 2 Radiant Flux Intensity

SQ 21.2.1 Define radiant flux intensity.

Definition

Radiant flux intensity is the amount of electromagnetic energy per unit area per unit time emitted from a star that reaches the Earth's surface.

SQ 21.2.2 Write the formula and unit of radiant flux intensity.

Formula

$$F = \frac{L}{4\pi r^2}$$

SI Unit

Its SI unit is watt per square metre $(\mathrm{W\,m^{-2}})$.

SQ 21.2.3 How is radiant flux intensity related to luminosity?

Answer

Radiant flux intensity is a small fraction of the total value of luminosity. In other words, it is the luminosity per unit area measured on the surface of the Earth.

SQ 21.2.4 Why does radiant flux intensity follow the inverse-square law?

Reason

As the luminosity of a star remains constant, the same energy spreads over a sphere whose area increases as r^2. Therefore the intensity follows the inverse-square law with distance.

SQ 21.2.5 What happens to the flux when the distance from a star is doubled or tripled?

Answer

When the distance is doubled, the intensity reduces to one-fourth of its original value. When it is increased to three times, the flux decreases by a factor of nine.

SQ 21.2.6 **A star of L = 4.50 × 10^{26} W is 1.40 × 10^{11} m away. Find the radiant flux intensity.**

Solution

$$F = \frac{L}{4\pi r^2} = \frac{4.50 \times 10^{26}}{4\pi(1.40 \times 10^{11})^2}$$

Result

$F = 1.83 \times 10^3\,\mathrm{W\,m^{-2}}$

SQ 21.2.7 **If the Earth were twice as far from the Sun, how intense would sunlight be?**

Answer

The sunlight reaching it would be only one-fourth as intense. Such low energy might have made the evolution of life impossible.

TOPIC 3 Standard Candles

SQ 21.3.1 **Why is measuring cosmic distances essential?**

Answer

In astronomy, measuring the distances to stars and galaxies is essential for understanding the structure and expansion of the universe.

SQ 21.3.2 **Define standard candles.**

Definition

Standard candles are astronomical objects with known intrinsic brightness that serve as vital tools for measuring cosmic distances.

SQ 21.3.3 **How are standard candles used to find distance?**

Method

By comparing how bright a standard candle appears from the Earth, that is its apparent magnitude, to how bright it actually is, astronomers can calculate its distance using the inverse-square law of light.

SQ 21.3.4 **Give examples of standard candles.**

Examples

Cepheid variable stars and Type Ia supernovae, both of which have predictable luminosities that make them reliable distance indicators.

SQ 21.3.5 **Who discovered the basis of standard candles?**

Answer

The idea dates back to the 1910s, when Henrietta Swan Leavitt discovered that Cepheid variable stars pulse in a predictable way. Her work laid the foundation for measuring cosmic distances.

TOPIC 4 Blackbody Radiation

SQ 21.4.1 **What happens when an object is heated?**

Answer

When an object is heated it starts to glow and releases energy in the form of radiation. This radiation depends only on the temperature of the object, not on its material or shape.

SQ 21.4.2 **How does the colour of a heated object change with temperature?**

Answer

As the temperature increases, the colour changes from dull red to bright yellow and then to white, indicating that the radiation is shifting from longer wavelengths to shorter ones.

SQ 21.4.3 **Define a blackbody.**

Definition

A blackbody is one that absorbs all the radiations falling on it, and also emits radiations at all wavelengths perfectly.

SQ 21.4.4 **Give a practical example of a blackbody.**

Example

A good example of a blackbody is a hollow cavity with a small hole and blackened inner walls. The inner walls are coated with black carbon soot to help absorb radiation effectively and reflect it internally.

SQ 21.4.5 **Define blackbody radiation.**

Definition

When radiation enters through the small hole of the cavity, it bounces around inside and gets trapped. If the cavity is heated to a high enough temperature, it emits radiations of all wavelengths, known as blackbody radiation.

SQ 21.4.6 **What does the blackbody radiation curve show?**

Answer

When the intensity of the radiation is plotted against wavelength, the peak of the curve shifts to shorter wavelengths with rising temperature. This means hotter blackbodies emit more energy at shorter wavelengths.

SQ 21.4.7 **Why do stars behave like blackbody radiators?**

Answer

Stars such as the Sun generate and emit their own energy due to nuclear fusion. The radiation covers a wide range of wavelengths and forms a continuous spectrum without any gaps, similar to a blackbody spectrum.

SQ 21.4.8 **How is the surface temperature of a star estimated?**

Answer

By studying the spectrum, scientists can estimate the surface temperature of the star accurately. As each star has its own spectrum, its surface temperature is also different.

SQ 21.4.9 **State Wien's displacement law.**

Statement

The wavelength corresponding to the radiation of maximum intensity emitted by a blackbody is inversely proportional to its surface temperature.

Formula

$\lambda_{max} T = b$

SQ 21.4.10 **Write the value of Wien's constant.**

Value

$b = 2.9 \times 10^{-3}\,\mathrm{m\,K}$

SQ 21.4.11 What does Wien's law tell us about the colour of objects?

Answer
Hotter objects emit radiations with shorter wavelengths, appearing blue or violet, while cooler objects emit radiations with longer wavelengths, appearing red or infrared.

SQ 21.4.12 A star at 6000 K peaks at 480 nm. Find the temperature of a star peaking at 320 nm.

Solution
Using
$\lambda_1 T_1 = \lambda_2 T_2$
therefore
$T_2 = \frac{\lambda_1 T_1}{\lambda_2}$

Calculation
$T_2 = \frac{480 \times 10^{-9} \times 6000}{320 \times 10^{-9}}$

Result
$T_2 = 9000\,\mathrm{K}$

SQ 21.4.13 Which glows hotter, a red-hot or a white-hot object?

Answer
The white-hot object is hotter, because by Wien's law a higher temperature shifts the peak radiation to shorter wavelengths, giving a whiter appearance.

TOPIC 5 Radius of a Star

SQ 21.5.1 How is the radius of a star calculated?

Method
The radius of a star can be calculated using Wien's displacement law and the Stefan-Boltzmann law together.

SQ 21.5.2 Describe the steps to determine the radius of a star.

Steps
The surface temperature of the star is first determined using Wien's displacement law.
The luminosity is calculated using the radiant flux intensity.
Stefan-Boltzmann's law is then used to determine the radius of the star.

SQ 21.5.3 Write the formula used to find the radius of a star.

Formula
$r = \sqrt{\frac{L}{4\pi\sigma T^4}}$

TOPIC 6 Emission and Absorption Spectra from Different Stars

SQ 21.6.1 Why do stars emit a continuous spectrum?

Reason
Stars emit a continuous spectrum of light because of their extremely hot, dense surfaces that behave like near-perfect blackbodies.

SQ 21.6.2 How is an absorption spectrum formed?

Formation
As the light passes through the cooler outer atmosphere of a star, atoms in the gaseous layers absorb specific wavelengths corresponding to electronic transitions between energy levels.

Result
This creates dark lines in the continuous spectrum where specific colours of light have been absorbed.

SQ 21.6.3 Why do we detect absorption lines rather than emission lines from a star?

Reason
Although the absorbed energy is re-emitted at the same wavelengths, the emitted photons are scattered in various directions, making them unlikely to reach observers on the Earth.

SQ 21.6.4 What is observed in the spectra of distant stars and galaxies?

Answer
The lines in the spectra show an increase in wavelength from their known laboratory values. This phenomenon is called redshift, which occurs due to the stretching of photons as they travel through the universe.

SQ 21.6.5 How does spectral analysis reveal the composition of a star?

Answer
Every star has its own light signature. By studying the emission and absorption spectra, scientists can determine what elements a star is made of.

TOPIC 7 Cosmic Redshift

SQ 21.7.1 Define cosmic redshift.

Definition
Cosmic redshift refers to the effect in which light coming from distant galaxies across the universe is stretched toward the red end of the spectrum.

SQ 21.7.2 Why does cosmic redshift happen?

Reason
This happens because the universe is expanding, causing galaxies to move away from us. As a result, the wavelength of light emitted by the galaxies increases.

SQ 21.7.3 What is the relation between distance and redshift?

Answer
The greater the distance of a galaxy, the larger its redshift, which means it is moving away faster.

SQ 21.7.4 Write the formula for redshift.

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

SQ 21.7.5 **Differentiate between redshift and blue shift.**

Redshift	Blue Shift
The observed change in wavelength is positive.	The observed change in wavelength is negative.
The celestial object is moving away from the Earth.	The object is approaching the Earth.

SQ 21.7.6 **Why does space itself cause the redshift?**

Reason

Space itself is stretching as the universe expands, which also stretches the light waves and makes their wavelengths longer. It is not just that galaxies are moving apart through space, rather the space between them is increasing.

SQ 21.7.7 **What does the redshift pattern in all directions indicate?**

Answer

The redshift pattern is observed in all directions, which indicates the expansion of the universe.

SQ 21.7.8 **Which theory is supported by cosmic redshift?**

Answer

These findings strongly support the Big Bang Theory, which suggests that the universe originated from an extremely hot and dense state and has been growing ever since.

TOPIC 8 Hubble's Law

SQ 21.8.1 **What did Edwin Hubble demonstrate?**

Answer

Edwin Hubble established the foundation for modern cosmology by demonstrating that galaxies are moving away from the Earth, and that their velocity increases with distance.

SQ 21.8.2 **State Hubble's law.**

Statement

The recession velocity of a galaxy is directly proportional to its distance from the Earth.

Formula

$v = H_0 d$

SQ 21.8.3 **Write the value of Hubble's constant.**

Value

$H_0 = 2.3 \times 10^{-18}\,\text{s}^{-1}$

SQ 21.8.4 **What does the graph of Hubble's law show?**

Answer

The graph reveals a direct and linear relationship between recession velocity and distance. The slope of this linear trend corresponds to the Hubble constant, which quantifies the rate of cosmic expansion.

SQ 21.8.5 **Explain the balloon model of the expanding universe.**

Model

The dots marked on the surface of an inflated balloon represent the galaxies, and the skin of the balloon represents four dimensional space-time.

Result

As the balloon is inflated, every dot sees the other dots moving away, similar to how galaxies move apart in space.

SQ 21.8.6 **What two main ideas does the balloon model explain?**

Ideas

No matter where we are in the universe, we would see galaxies moving away from us.
The expansion is happening everywhere and there is no special centre, so the Earth is not at the centre of the universe.

SQ 21.8.7 **What is implied by reversing time in an expanding universe?**

Implications

In the past galaxies were closer together.
Going further back, all matter was compressed into a very small, dense and hot state.

SQ 21.8.8 **When did the universe begin according to the Big Bang Theory?**

Answer

The Big Bang Theory proposes that the universe began from an initial singularity about 13.8 billion years ago and has been expanding ever since.

SQ 21.8.9 **What did scientists think before Hubble's discovery?**

Answer

Before Hubble's discovery most scientists thought the universe was static. Hubble's law turned that idea on its head, suggesting the universe had a beginning.

TOPIC 9 Earth's Climate System

SQ 21.9.1 **What is the Earth's climate system?**

Definition

Earth's climate system is the long-term pattern of temperature, rainfall, wind and other weather conditions in a region. It affects all living things and natural systems on our planet.

SQ 21.9.2 **By what is the climate shaped?**

Answer

The climate is shaped by natural factors, like the Sun and ocean currents, and by human activities such as burning fossil fuels and cutting down forests.

SQ 21.9.3 **Name the five components of the Earth's climate system.**

Components

The atmosphere, that is air.
The hydrosphere, that is water.
The cryosphere, that is ice and permafrost.
The lithosphere, that is the Earth's upper rocky layer.
The biosphere, that is living things.

SQ 21.9.4 How do the components of the climate system interact?

Answer
These components work together and affect each other. Changes in one part can cause changes in the others.

SQ 21.9.5 Why is understanding the climate important?

Answer
Understanding the climate of the Earth helps us to prepare for and to reduce the impacts of climate change.

TOPIC 10 Ocean Currents and Wind Patterns

SQ 21.10.1 How does seawater circulate?

Answer
Seawater circulates in two main ways, that is across the surface and between the deeper layers.

SQ 21.10.2 What causes surface ocean currents?

Answer
Surface currents are mostly caused by wind, pushing water across the ocean's top layer.

SQ 21.10.3 What drives the vertical circulation of water?

Answer
The vertical circulation of water is called thermohaline circulation. It is driven by differences in water temperature and salinity, which together affect its density.

SQ 21.10.4 What are gyres and in which directions do they spin?

Definition
The rotation of the Earth shapes ocean movement, creating large circular current systems known as gyres.

Direction
They spin clockwise in the northern hemisphere and anticlockwise in the southern hemisphere.

SQ 21.10.5 How do ocean currents help regulate the climate?

Answer
The currents move warm water from the equator toward the poles and bring cold water back, helping to regulate the climate of the planet.

SQ 21.10.6 How are wind patterns created?

Answer
Wind patterns are created due to the uneven heating of the Earth's surface. This causes warm air to rise and cooler air to move in, forming distinct wind belts.

SQ 21.10.7 Name the main wind belts.

Answer
The main wind belts are the trade winds, the westerlies and the polar easterlies.

SQ 21.10.8 What is the combined effect of winds and ocean currents?

Answer
Together, wind patterns and ocean currents help distribute heat and energy across the planet, affecting climate zones and weather patterns.

TOPIC 11 Global Climate and Energy Transfer from the Sun

SQ 21.11.1 Define the Earth's energy budget.

Definition
The Earth's energy budget refers to the balance between the solar energy absorbed by the Earth and the energy it radiates back into space.

SQ 21.11.2 What happens to the energy budget when the Earth is colder?

Answer
When the Earth is colder, more ice and snow cover the surface. Ice and snow are bright and reflect a large amount of sunlight back into space, which makes the Earth even cooler.

SQ 21.11.3 What happens to the energy budget when the Earth gets warmer?

Answer
Ice and snow start to melt, exposing darker surfaces like land and oceans, which absorb more sunlight and reflect less. As a result the Earth becomes warmer.

SQ 21.11.4 How much of the Sun's energy does the Earth absorb?

Answer
The Earth only absorbs about 70% of the Sun's energy. The rest is reflected back into space by clouds, ice and desert surfaces. A 1% imbalance can lead to major global temperature shifts.

SQ 21.11.5 When does the temperature of the Earth remain constant?

Answer
The energy coming in from the Sun is balanced by the energy going out from the Earth in the form of infrared radiations. When this balance is maintained, the temperature remains constant over time.

SQ 21.11.6 What causes global warming?

Answer
Greenhouse gases trap infrared radiations, preventing them from escaping into space. As a result the Earth is warming up, a problem known as global warming.

SQ 21.11.7 Why is there an energy imbalance between the poles and the equator?

Reason
The equator receives direct, intense sunlight, causing warm air to rise and form low pressure zones, while the poles get slanted, weaker sunlight, leading to cold, sinking air and high pressure zones.

SQ 21.11.8 **What does the energy imbalance drive?**

Answer
This energy imbalance drives global atmospheric circulation, creating wind patterns like the trade winds near the equator, westerlies in mid-latitudes, and polar easterlies near the poles.

TOPIC 12 Atmospheric Circulation and Atmospheric Cells

SQ 21.12.1 **Write the specific angular momentum of an air mass.**

Formula
$L' = rv$
Here specific angular momentum is the angular momentum per unit mass.

SQ 21.12.2 **Why does air speed up as it moves toward the poles?**

Reason
As air moves from the equator toward the poles it retains its specific angular momentum. As the distance r from the rotation axis decreases, the velocity v must increase to keep rv constant.

SQ 21.12.3 **Define the Coriolis effect.**

Definition
The Earth rotates faster at the equator than at higher latitudes, so air moving toward the pole lags behind the rotation of the surface beneath it. This apparent deflection of the moving air is called the Coriolis effect.

SQ 21.12.4 **In which direction does the Coriolis deflection occur?**

Answer
The deflection occurs toward the right in the northern hemisphere and to the left in the southern hemisphere.

SQ 21.12.5 **Does the Coriolis effect change the speed of the air?**

Answer
No. This deflection does not affect the speed of the air, but changes its path, creating curved wind patterns.

SQ 21.12.6 **Name the three atmospheric circulation cells.**

Cells
The deflected air flows lead to the formation of three distinct atmospheric circulation cells in each hemisphere, namely the Hadley cell, the Ferrel cell and the Polar cell.

TOPIC 13 Role of Salt and Density in Ocean Circulation

SQ 21.13.1 **Define salinity.**

Definition
Ocean water contains a variety of dissolved substances, with salt being the most abundant. The amount of salt in ocean water is called salinity.

SQ 21.13.2 **Why does higher salinity give higher density?**

Reason
The dissolved salt increases the mass of the water without significantly increasing its volume. As a result, higher salinity leads to higher water density.

SQ 21.13.3 **What drives ocean circulation in deep waters?**

Answer
Density differences between water masses are one of the key forces driving ocean circulation, especially in deep waters. These differences arise mainly due to variations in temperature and salinity.

SQ 21.13.4 **Which water is denser?**

Answer
Cold water is denser than warm water, and salty water is denser than less salty water.

SQ 21.13.5 **How do deep ocean currents form?**

Formation
When surface waters become colder and saltier, often due to evaporation or the formation of sea ice, they become denser and sink to deeper layers.

Result
As denser water sinks it pushes other water out of the way, creating slow-moving but large-scale currents.

SQ 21.13.6 **What is the importance of deep ocean circulation?**

Answer
This deep circulation helps transport heat and gases such as oxygen and carbon dioxide around the globe. It connects surface and deep water systems and plays an important role in regulating the Earth's climate.

SQ 21.13.7 **Why do people float effortlessly in the Dead Sea?**

Answer
The Dead Sea is so salty that its density is extremely high due to the salt concentration, so the upthrust on a person is large enough to make them float effortlessly.

TOPIC 14 Thermohaline Circulation

SQ 21.14.1 **Define thermohaline circulation.**

Definition
Thermohaline circulation, often referred to as the global conveyor belt, is a crucial process in the Earth's oceans that helps transport heat from the tropical regions to the poles.

SQ 21.14.2 **What drives thermohaline circulation?**

Answer
This circulation is driven by variations in water temperature and salinity, which together affect the density of the seawater.

SQ 21.14.3 **Describe the movement of water in thermohaline circulation.**

Movement

Warm, less dense water near the equator moves along the surface toward the polar regions, carrying heat energy.
In polar areas the water cools and becomes denser due to lower temperature and increased salinity from sea ice formation, causing it to sink and flow back toward the equator at deeper levels.

SQ 21.14.4 **What is the importance of thermohaline circulation?**

Answer

This continuous movement helps regulate the Earth's climate, influences atmospheric patterns, and supports marine ecosystems by redistributing heat and nutrients globally.

SQ 21.14.5 **How long does one full cycle of the global conveyor belt take?**

Answer

The complete three-dimensional circulation takes approximately 1000 years to cycle water through all the world's ocean basins.

SQ 21.14.6 **What could happen if global warming slows thermohaline circulation?**

Answer

If global warming slows it down, Europe could face a mini-ice age, even while the rest of the world heats up.

TOPIC 15 Satellite Remote Sensing

SQ 21.15.1 **Define satellite remote sensing.**

Definition

Satellite remote sensing is a technology that uses sensors aboard orbiting spacecraft to monitor and analyze the Earth's environment from space.

SQ 21.15.2 **What phenomena can satellite remote sensing track?**

Answer

It enables scientists to track phenomena such as deforestation, climate change, ocean temperatures and atmospheric composition.

SQ 21.15.3 **What advantage does remote sensing have over ground-based methods?**

Answer

Unlike ground-based methods, it offers wide geographic coverage and repeated observations over time, making long-term environmental monitoring possible.

SQ 21.15.4 **Describe the source and illumination step of remote sensing.**

Step

The first and foremost element is the source or illumination, which illuminates the target. It is in the form of electromagnetic radiation.

SQ 21.15.5 **Describe the atmospheric interaction step of remote sensing.**

Step

After radiations are emitted from the source, they interact with the atmosphere. This interaction may be in the form of scattering or reflection.

SQ 21.15.6 **Describe the interaction with target step.**

Step

After atmospheric interaction comes interaction with the target of interest. This interaction depends on the properties of the target and of the radiation.

SQ 21.15.7 **Describe the recording with sensor step.**

Step

The emitted or reflected radiations from the target are recorded by sensors, which are remote, that is not in contact with the target.

SQ 21.15.8 **Describe the transmission and reception step.**

Step

The recorded radiations from the sensor are then transmitted to the reception station, to convert the data into an understandable form such as images.

SQ 21.15.9 **Describe the interpretation and analysis step.**

Step

The processed image is then interpreted, electronically or digitally, to get the required information.