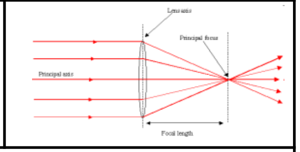
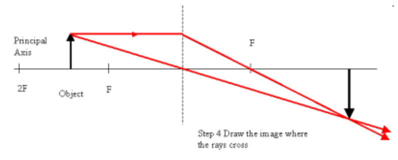
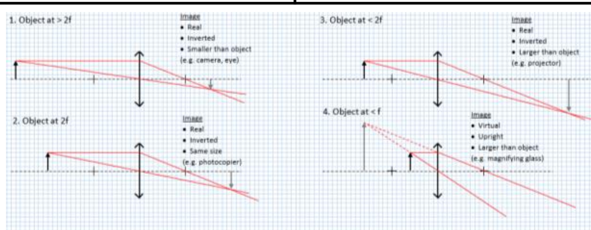
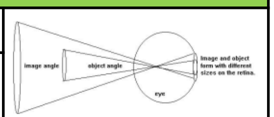
Subject: A-level Physics	Topic: Astrophysics	Year Group: 13

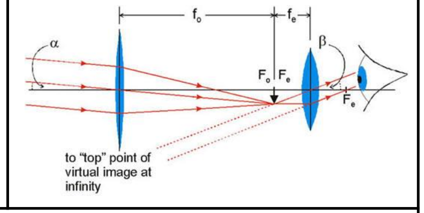
Ray diagrams

1	Convex lenses cause parallel rays of light to converge at the principal focus.	
2	This is a ray diagram for a convex lens to show how an image forms.	
3	Steps when drawing a ray diagram: a) Draw one ray from the top of the object travelling parallel to the principal axis until it reaches the lens. b) This ray then bends so that is passes through the principal focus on the other side of the lens. c) Draw another ray from the top of the object passing through the centre of the lens. This ray doesn't bend. d) Where the two rays intercept is the top of the image.	
4	Depending on where the object is in relation to the principal focus images can be either …	Magnified or diminished Upright or inverted Real or virtual
5		

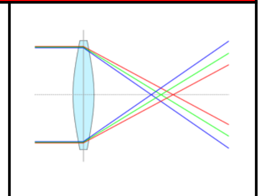
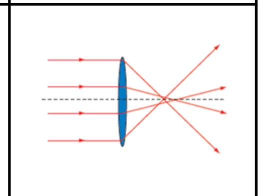
Magnification

1	f_o	Focal length of objective lens	
	f_e	Focal length of eyepiece lens	
	α	Angle subtended by the image to the unaided eye.	
	β	Angle subtended by the object to the eye.	

Refracting telescope

1	Ray diagram for refracting telescope in normal adjustment.	
2	Refracting telescopes use two convex lenses (the objective lens and the eyepiece lens).	
3	Normal adjusted means the lenses are set up so that the principal focus of the objective (1st) lens is in the same position as the principal focus of the eye lens (2nd).	
4	Length of a refracting telescope in normal adjustment = $f_o + f_e$	

Problems with refracting telescopes

1	Chromatic aberration: • Glass refracts different colours by different amounts (**blue more than red**). • The principal focus is different for each colour, blurring the image.	
2	Spherical aberration: • The curvature of the lens results in light rays in a parallel beam being focussed at slight different positions. • **Outer rays converge sooner than rays closer to centre.**	
3	Mounting the lens can only be done using the edge of the lens.	
4	Lenses are heavy and distort under their own weight.	
5	Large magnifications require long f_o and therefore long telescopes.	
6	Using glass of sufficient clarity and purity to make large diameter telescopes is extremely difficult.	

Key equations

1	Magnification	$M = \frac{f_o}{f_e} = \frac{\alpha}{\beta}$

Key Vocabulary

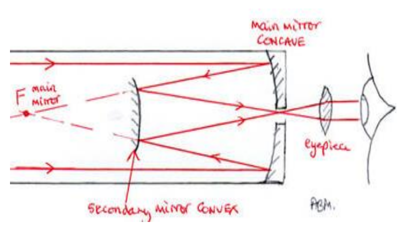
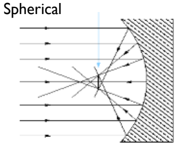
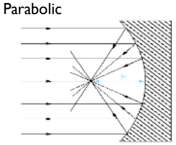
1	Principle axis	An axis of a lens that passes through its centre, perpendicular to its surface on both sides.
2	Lens axis	The axis passing through the centre of a lens perpendicular to its principal axis.
3	Principal focus	The point where incident rays parallel to the principal axis converge.
4	Focal length	The distance between the lens axis and the focal plane.
5	Focal plane	The plane perpendicular to the principal axis of a lens, on which the principal focus lies.
6	Real image	An image formed when light rays from a point on an object are made to pass through another point in space. The image can be captured on a screen.
7	Virtual image	An image formed when light rays from a point on an object appear to have come from another point in space. The image cannot be captured on a screen.
8	Chromatic aberration	Light of different wavelengths (colours) is refracted to different foci, resulting in the image for each colour being in a slightly different position.
9	Spherical aberration	Rays at different distances from the principal axis have different focal points, resulting in a blurring of the image.

Beckfoot

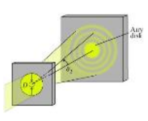
Subject: A-level Physics	Topic: Astrophysics	Year Group: 13

enjoy learn succeed

Reflecting telescopes

1	Reflecting telescopes use a concave mirror to converge incoming rays.	
2	In the **Cassegrain** arrangement a secondary **convex** mirror sends rays down an opening in the primary mirror. The image is then brought to a focus using an eyepiece or camera.	
3	It is important that the concave mirror is perfectly parabolic in shape to prevent spherical aberration.	Spherical  Parabolic 
4	Advantages of reflecting telescopes:	No chromatic aberration. No spherical aberration if using a parabolic mirror. Mirrors can be supported from behind.

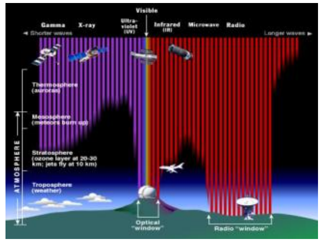
Resolving power

1	Resolving power is the ability to produce separate images of closely spaced objects.	
2	When waves pass through the opening of a telescope they diffract, producing a circular diffraction pattern.	
3	Telescopes do not focus the light from a star to a perfect point but to a disc called an Airy disc.	
4	For two objects to be resolved the centre of the Airy disc of one object must be at least as far away as the 1st minimum of the other source.	
5	The Rayleigh criterion allows us to determine the resolving power of a telescope.	θ – Minimum angle that can be resolved (rad) λ – Wavelength of radiation collected D – Diameter of mirror or lens
6	Two objects can be resolved if their angular separation is θ or greater. More desirable telescopes will have a smaller value for θ.	

Collecting power

1	Collecting power is the energy collected per second.
2	It is **proportional** to the area of the telescope's objective.
3	A bigger dish collects more photons and energy from an object in a given time meaning fainter objects can be detected.

Other telescopes

1	Telescopes can be built to detect types of radiation other than light. For example. Infra-red, UV, x-rays and radio waves.	
2	**Infra-red**	• Similar structures to optical reflecting telescopes. • Their detectors have to be kept very cold and away from other heat sources. • Since water vapour the atmosphere absorbs IR mainly used in space or at high altitudes. • There are some wavelengths where ground base measurements can be made.
3	**Radio wave**	• Use large, parabolic objective dishes to collect radio waves which are then reflected to a focus. • Are ground based since radio waves can pass through the atmosphere. • Operate day and night since they are not affected by visible light from the Sun. • Are positioned away from artificial sources of radio waves. • Because radio waves have long wavelengths these telescopes need very large diameters to have decent resolving powers. • Have good collecting powers since they have large diameters.
4	**UV and X-ray**	• Are positioned in space since the atmosphere absorbs these wavelengths.

Key equations

1	Collecting power	$Collecting\ power \propto area \propto diameter^2$
2	Rayleigh criterion	$\theta = \frac{\lambda}{D}$

Key Vocabulary

1	Collecting power	A measure of a telescope's ability to collect incident electromagnetic radiation.
2	Resolving power	A measure of the ability of a telescope to distinguish between adjacent astronomical features or objects,
3	Rayleigh criterion	Two objects will just be resolved when the first minimum in the diffraction pattern of one image coincides with the central maximum of the other.
4	Airy disc	The bright central region in an optical diffraction pattern caused by light entering a circular aperture.
5	Quantum efficiency	The ratio of the number of photons falling on a device that produce a signal to the total number of photons falling on the device.

CCDs

1	Charge-coupled devices are silicon chips which are divided into pixels.	
2	Light (photons) are focussed on the CCD which causes electrons to be released. The number of electrons released is proportional to the light intensity.	
3	The electrons are trapped in potential wells, building up an electron pattern.	
4	When exposure is complete the charge is processed to form an image.	
5	Advantages	High quantum efficiency (greater than 70 %). Can be linked directly to a computer.

Subject: A-level Physics | Topic: Astrophysics | Year Group: 13

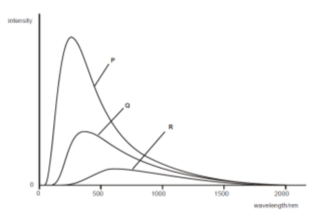
Beckfoot — enjoy learn succeed

Luminosity and absolute magnitude

1	In **120 BC** the astronomer **Hipparcos** ranked the brightness of over 1000 stars as seen from Earth on a 1 (brightest) to 6 (dimmest) scale.
2	Magnitude 1 stars are 100 times brighter than magnitude 6 stars. So an increase of 1 on the 1-6 scale corresponds to an increase in light received by 2.51, i.e. $100^{1/5}$.
3	Over time this scale has been developed. It is called the apparent magnitude scale.
4	Apparent magnitude is how bright a star appears on Earth. It depends on how bright the star actually is and how far away it is.
5	Larger values of apparent magnitude are given to dimmer stars.
6	The apparent magnitude scale runs from -26 (our Sun) to approaching +30 (stars visible to only the largest telescopes).

Black bodies

1	A black body is a theoretical object that absorbs all the light that hits it, so it appears perfectly black when cold. When heated above absolute zero, it emits light across the whole EM spectrum, in a distribution that looks like this.



2	Stars are approximate black bodies.
3	A hotter black body will emit more radiation at shorter wavelengths than cooler ones since E=hc/λ..
4	So as T increases λ_{max} (peak wavelength) decreases.
5	Wien's law states, **$\lambda_{max}T$ = 0.0029 mK** (where mK stands for metres Kelvin).
6	The luminosity of a star is a measure of the energy it emits per second. It depends on the star's size and temperature.
7	Stefan's law states, $P = \sigma A T^4$

P	Luminosity (power) of star
σ	Stefan's constant
A	Surface area of star
T	Temperature of star

Distances to stars

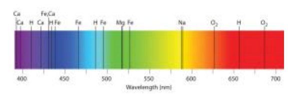
1	The distance to a star can be determined by comparing its apparent and absolute magnitude.
2	$m - M = 5\log\left(\frac{d}{10}\right)$

m	Apparent magnitude
M	Absolute magnitude
d	Distance to the object in parsecs.

3
- Stars which are closer than 10 pc have a brighter (more negative) apparent magnitude than absolute magnitude. m-M < 0
- Stars further than 10 pc have a dimmer (more positive) apparent magnitude than absolute magnitude. m-M > 0
- If m = M the star must be at a distance of 10 pc from Earth.

Spectral classes

1	The light we detect from stars has absorption lines in. These can be used to determine the T of the star.



2	The hydrogen absorption lines in the visible part of the spectrum are caused by electrons moving from n = 2 to higher levels. These are lines are called **Balmer lines**.
3	So if Balmer lines are seen in the visible spectrum the star must be hot since the electrons have already been excited to n = 2.
4	However, if the star was really hot then the electrons would exist in higher excited states (n > 2) and we would not see Balmer lines.
5	This means there are only a range of T for which Balmer lines can be seen so if we can see them we know roughly how hot the star is.
6	Stars are put into spectral classes based on their absorption spectra.

Spectral Class	Intrinsic Colour	Temperature/K	Prominent Absorption Lines
O	blue	25000 – 50000	He+, He, H
B	blue	11000 – 25000	He, H
A	blue-white	7500 – 11000	H (strongest) ionised metals
F	white	6000 – 7500	ionised metals
G	yellow-white	5000 – 6000	ionised & neutral metals
K	orange	3500 – 5000	neutral metals
M	red	< 3500	neutral atoms, TiO

7	One way to remember the order of the spectral classes is using the mnemonic 'Oh be a fine girl, kiss me'.

Key equations

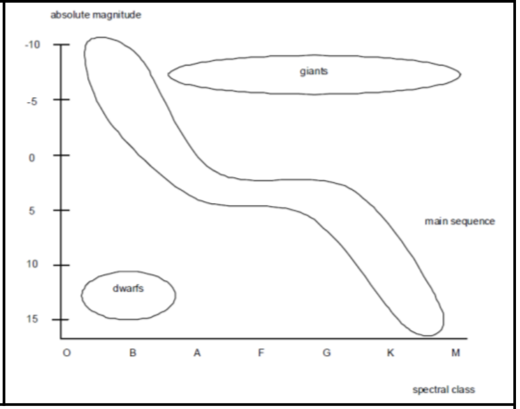
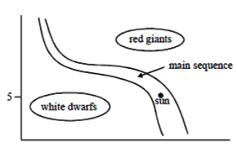
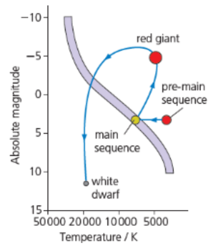
1	Magnitude equation	$m - M = 5\log\left(\frac{d}{10}\right)$
2	Wien's law	$\lambda_{max}T = 0.0029$ mK
3	Stefan's law	$P = \sigma A T^4$

Key Vocabulary

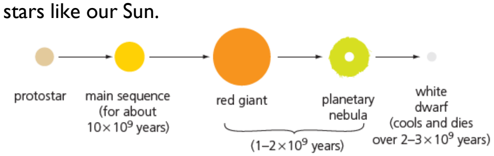
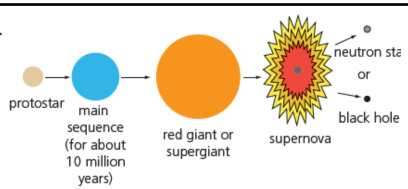
1	Luminosity	The total energy emitted per second.
2	Intensity	The amount of energy radiated per second per square metre. Also called brightness.
3	Apparent magnitude	Brightness of a star as seen from Earth.
4	Absolute magnitude	Brightness (or apparent magnitude) of a star from a distance of 10 parsecs.
5	Parsec	The distance at which 1 AU subtends an angle of 1 arc second.
6	Light year	The distance travelled by light through a vacuum in one year.
7	Astronomical unit	The average distance between the Earth and the Sun.
8	Wien's law	For a hot object, the wavelength of the peak emission intensity is inversely proportional to the absolute temperature of the object.
9	Stefan's law	The total energy emitted per square metre per second from an object at a given temperature T is proportional to T^4.
10	Absorption spectrum	A pattern of dark spectral lines in a continuous spectrum produced by the absorption of photons of precise energy.

Subject: A-level Physics	Topic: Astrophysics	Year Group: 13

Hertzsprung-Russell diagrams

1	y-axis: from 15 to -10. x-axis: from O to M OR from 50 000 K to 2500K.	
2	Note the temperature axis is back to front in that it goes from hot to cold.	
3	The Sun is in spectral class G and has an absolute magnitude of ~5. Far right shows how the Sun's position will change as it evolves.	 

Stellar evolution

1	Low mass stars like our Sun. 
2	High mass stars. 

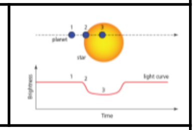
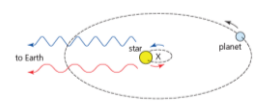
Supernovae, neutron stars and black holes

1	Supernovae occur when a high mass star explodes, releasing massive amounts of energy (10^{46} J).
2	Certain supernovae (Type 1a) always produce the same peak in absolute magnitude (-19.3). They are standard candles.
3	They are used to estimate cosmological distances by measuring their apparent magnitude and using the magnitude equation.
4	After a supernova you are left with a neutron star - a star composed entirely of neutrons. Typical diameter for a neutron star is 20 km.
5	For extremely massive stars gravity continues to compress the neutron star until a black hole forms.
6	It is believed supermassive black holes exist at the centre of galaxies.

Quasars

1	Quasars are star like objects with unusually strong radio emissions.
2	They are very luminous and their absorption spectra show massive red-shifts, meaning they have very high recessional velocities and are very far away (possibly most distant objects in the universe).
3	It is thought that quasars are part of 'active galactic nuclei'. As particles fall into the supermassive black hole at the galaxy's centre energy is released in the form of EM radiation.

Exoplanets

1	There are two main ways they can be detected.	
2	**Transit method:** Works by detecting a dip in the star's brightness as an exoplanet moves in front of it.	
3	**Radial velocity method:** Works by detecting periodic variations in a star's absorption spectra. Planets don't really orbit stars, they both orbit their common centre of mass. The star will be observed to wobble (from its absorption spectra) as it moves about this point.	 *Figure 18* A star–planet system orbits around its centre of mass indicated by X

Key equations

1	Schwarzschild radius	$R_s = \frac{2GM}{c^2}$

Key Vocabulary

1	Standard candle	An objects whose absolute magnitude is known and whose apparent magnitude can be measured.
2	Supernova	A star whose luminosity increases enormously due to it exploding.
3	Neutron star	A star with the density of nuclear matter.
4	Black hole	An object whose escape velocity is greater than the speed of light.
5	Red giant	A large, relatively cool star of high luminosity, similar is mass to our Sun but with greatly expanded outer shell.
6	White dwarf	A low mass, small star that has exhausted all its nuclear fuel.
7	Supergiant	Highly luminous stars with masses 10 – 100 times that of the Sun and high core temperatures.
8	Escape velocity	The velocity an object would need to travel at to escape a gravitational field.
9	Event horizon	The boundary where the escape velocity is c.
10	Schwarzschild radius	The radius of an imaginary sphere from the centre of a black hole at which the escape velocity is equal to c.
11	Exoplanet	Planet that orbit a star other than our Sun.
12	Red-shift	The increase in wavelength of radiation that is emitted by an object that is moving away from an observer.

Subject: A-level Physics	Topic: Astrophysics	Year Group: 13

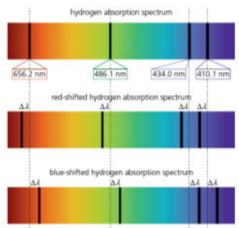
Doppler effect

1	Doppler shift is the change in frequency of waves emitted by an object as it moves towards or away from an observer.

2

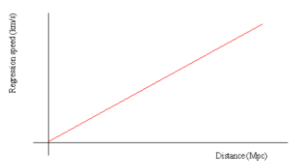
$$z = \frac{\Delta\lambda}{\lambda} = -\frac{\Delta f}{f} = -\frac{v}{c}$$

z	Red/doppler shift
λ	Actual wavelength of line
λ_{app}	Apparent wavelength of the line as viewed from Earth
v	Relative velocity of approach of Earth and the star. It is positive when two objects are approaching and negative when they are receding.



Hubble's law

1	Hubble used type 1a supernova to measure the distances to some galaxies. He also measured the red-shift of some galaxies.
2	He found the rate at which a galaxy recedes is directly proportional to its distance from us.



3 $v = H_0 d$

v	Recession velocity in km s^{-1}
H_0	Hubble's Constant in km s^{-1} Mpc^{-1}
d	Distance to the galaxy in Mpc

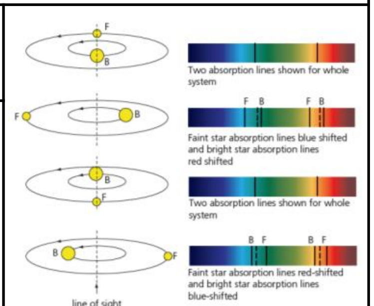
4	Hubble's constant can be used to estimate the age of the universe.
5	To determine the age of the universe convert the value for Hubble's constant into s^{-1}. Then take the reciprocal.

The Big Bang

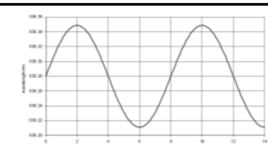
1	The big bang theory states that the universe began 14 billion years ago from hot, dense point that started to expand.	
2	The three pieces of evidence supporting this are:	Expansion of universe (Hubble's law)
		Cosmic microwave background radiation (CMBR)
		Relative abundance of hydrogen and helium

Binary stars

1	Binary star systems consist of two stars orbiting their common centre of mass.
2	These systems can be difficult to observe because the stars are close together so we need telescopes with good resolving power to observe them.
3	Position 1 - the there are two absorption lines as both stars are in line.
	Position 2 - the light coming from star B is red-shifted as B is moving away from us. The light coming from star F is blue shifted as it moving towards us. And so on.



4 This graph shows how the wavelength of light from one of the stars would vary as the stars orbit their common centre of mass



Key equations

1	Doppler equation	$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{app} - \lambda}{\lambda} = -\frac{v}{c}$
2	Red shift	$z = \frac{\Delta\lambda}{\lambda} = -\frac{\Delta f}{f} = -\frac{v}{c}$
3	Hubble's law	$v = H_0 d$
4	Age of universe	$Age\ of\ universe = \frac{1}{H_0}$

Key Vocabulary

1	Doppler effect	The change in frequency and wavelength of radiation due to the relative motion of a source and observer.
2	Recession velocity	The rate at which an object is moving away from Earth.
3	Hubble's law	The rate at which a galaxy recedes is directly proportional to its distance from us.
4	CMBR	Isotropic radiation in the microwave region with a black-body temperature of 2.7 K.
5	Dark energy	A hypothetical form of energy that permeates all space and tends to increase the rate of expansion of the universe.
6	Dark matter	Unobserved matter that is believed to be abundant within galaxies throughout the universe.
7	Big Bang theory	The explosion event that occurred about 14 billiion years ago that is considered the beginning of the universe.