Redshift

In physics , redshift happens when light or other electromagnetic radiation from an object is increased in wavelength , or shifted to the red end of the spectrum . In general , whether or not the radiation is within the visible spectrum , " redder " means an increase in wavelength ? equivalent to a lower frequency and a lower photon energy , in accordance with , respectively , the wave and quantum theories of light .
Some redshifts are an example of the Doppler effect , familiar in the change of apparent pitches of sirens and frequency of the sound waves emitted by speeding vehicles . A redshift occurs whenever a light source moves away from an observer . Another kind of redshift is cosmological redshift , which is due to the expansion of the universe , and sufficiently distant light sources (generally more than a few million light years away) show redshift corresponding to the rate of increase in their distance from Earth . Finally , gravitational redshift is a relativistic effect observed in electromagnetic radiation moving out of gravitational fields . Conversely , a decrease in wavelength is called blueshift and is generally seen when a light @-@ emitting object moves toward an observer or when electromagnetic radiation moves into a gravitational field . However , redshift is a more common term and sometimes blueshift is referred to as negative redshift .
Knowledge of redshifts and blueshifts has been applied to develop several terrestrial technologies such as Doppler radar and radar guns . Redshifts are also seen in the spectroscopic observations of astronomical objects . Its value is represented by the letter z .
A special relativistic redshift formula (and its classical approximation) can be used to calculate the redshift of a nearby object when spacetime is flat . However , in many contexts , such as black holes and Big Bang cosmology , redshifts must be calculated using general relativity . Special relativistic , gravitational , and cosmological redshifts can be understood under the umbrella of frame transformation laws . There exist other physical processes that can lead to a shift in the frequency of electromagnetic radiation , including scattering and optical effects ; however , the resulting changes are distinguishable from true redshift and are not generally referred to as such (see section on physical optics and radiative transfer) .

History

The history of the subject began with the development in the 19th century of wave mechanics and the exploration of phenomena associated with the Doppler effect . The effect is named after Christian Doppler , who offered the first known physical explanation for the phenomenon in 1842 . The hypothesis was tested and confirmed for sound waves by the Dutch scientist Christophorus Buys Ballot in 1845 . Doppler correctly predicted that the phenomenon should apply to all waves , and in particular suggested that the varying colors of stars could be attributed to their motion with respect to the Earth . Before this was verified , however , it was found that stellar colors were primarily due to a star 's temperature , not motion . Only later was Doppler vindicated by verified redshift observations .
The first Doppler redshift was described by French physicist Hippolyte Fizeau in 1848 , who pointed to the shift in spectral lines seen in stars as being due to the Doppler effect . The effect is sometimes called the " Doppler ? Fizeau effect " . In 1868 , British astronomer William Huggins was the first to determine the velocity of a star moving away from the Earth by this method . In 1871 , optical redshift was confirmed when the phenomenon was observed in Fraunhofer lines using solar rotation , about 0 @.@ 1 Å in the red . In 1887 , Vogel and Scheiner discovered the annual Doppler effect , the yearly change in the Doppler shift of stars located near the ecliptic due to the orbital velocity of the Earth . In 1901 , Aristarkh Belopolsky verified optical redshift in the laboratory using a system of rotating mirrors .
The earliest occurrence of the term " red @-@ shift " in print (in this hyphenated form) appears to be by American astronomer Walter S. Adams in 1908 , in which he mentions " Two methods of investigating that nature of the nebular red @-@ shift " . The word does not appear unhyphenated until about 1934 by Willem de Sitter , perhaps indicating that up to that point its German equivalent ,

Rotverschiebung , was more commonly used .

Beginning with observations in 1912 , Vesto Slipher discovered that most spiral galaxies , then mostly thought to be spiral nebulae , had considerable redshifts . Slipher first reports on his measurement in the inaugural volume of the Lowell Observatory Bulletin . Three years later , he wrote a review in the journal Popular Astronomy . In it he states , " [...] the early discovery that the great Andromeda spiral had the quite exceptional velocity of ? 300 km (/ s) showed the means then available , capable of investigating not only the spectra of the spirals but their velocities as well . " Slipher reported the velocities for 15 spiral nebulae spread across the entire celestial sphere , all but three having observable " positive " (that is recessional) velocities . Subsequently , Edwin Hubble discovered an approximate relationship between the redshifts of such " nebulae " and the distances to them with the formulation of his eponymous Hubble 's law . These observations corroborated Alexander Friedmann 's 1922 work , in which he derived the famous Friedmann @-@ Lemaître equations . They are today considered strong evidence for an expanding universe and the Big Bang theory .

= = Measurement , characterization , and interpretation = =

The spectrum of light that comes from a single source (see idealized spectrum illustration top @-@ right) can be measured . To determine the redshift , one searches for features in the spectrum such as absorption lines , emission lines , or other variations in light intensity . If found , these features can be compared with known features in the spectrum of various chemical compounds found in experiments where that compound is located on Earth . A very common atomic element in space is hydrogen . The spectrum of originally featureless light shone through hydrogen will show a signature spectrum specific to hydrogen that has features at regular intervals . If restricted to absorption lines it would look similar to the illustration (top right) . If the same pattern of intervals is seen in an observed spectrum from a distant source but occurring at shifted wavelengths , it can be identified as hydrogen too . If the same spectral line is identified in both spectra ? but at different wavelengths ? then the redshift can be calculated using the table below . Determining the redshift of an object in this way requires a frequency- or wavelength @-@ range . In order to calculate the redshift one has to know the wavelength of the emitted light in the rest frame of the source , in other words , the wavelength that would be measured by an observer located adjacent to and comoving with the source . Since in astronomical applications this measurement cannot be done directly , because that would require travelling to the distant star of interest , the method using spectral lines described here is used instead . Redshifts cannot be calculated by looking at unidentified features whose rest @-@ frame frequency is unknown , or with a spectrum that is featureless or white noise (random fluctuations in a spectrum) .

Redshift (and blueshift) may be characterized by the relative difference between the observed and emitted wavelengths (or frequency) of an object . In astronomy , it is customary to refer to this change using a dimensionless quantity called z . If ? represents wavelength and f represents frequency (note , ?f = c where c is the speed of light) , then z is defined by the equations :

After z is measured , the distinction between redshift and blueshift is simply a matter of whether z is positive or negative . See the formula section below for some basic interpretations that follow when either a redshift or blueshift is observed . For example , Doppler effect blueshifts ($z < 0$) are associated with objects approaching (moving closer to) the observer with the light shifting to greater energies . Conversely , Doppler effect redshifts ($z > 0$) are associated with objects receding (moving away) from the observer with the light shifting to lower energies . Likewise , gravitational blueshifts are associated with light emitted from a source residing within a weaker gravitational field as observed from within a stronger gravitational field , while gravitational redshifting implies the opposite conditions .

= = Redshift formulae = =

In general relativity one can derive several important special @-@ case formulae for redshift in certain special spacetime geometries , as summarized in the following table . In all cases the magnitude of the shift (the value of z) is independent of the wavelength .

= = = Doppler effect = = =

If a source of the light is moving away from an observer , then redshift (z > 0) occurs ; if the source moves towards the observer , then blueshift (z < 0) occurs . This is true for all electromagnetic waves and is explained by the Doppler effect . Consequently , this type of redshift is called the Doppler redshift . If the source moves away from the observer with velocity v , which is much less than the speed of light (v ? c) , the redshift is given by
<formula> (since <formula>)
where c is the speed of light . In the classical Doppler effect , the frequency of the source is not modified , but the recessional motion causes the illusion of a lower frequency .
A more complete treatment of the Doppler redshift requires considering relativistic effects associated with motion of sources close to the speed of light . A complete derivation of the effect can be found in the article on the relativistic Doppler effect . In brief , objects moving close to the speed of light will experience deviations from the above formula due to the time dilation of special relativity which can be corrected for by introducing the Lorentz factor ? into the classical Doppler formula as follows (for motion solely in the line of sight) :
<formula>
This phenomenon was first observed in a 1938 experiment performed by Herbert E. Ives and G.R. Stilwell , called the Ives ? Stilwell experiment .
Since the Lorentz factor is dependent only on the magnitude of the velocity , this causes the redshift associated with the relativistic correction to be independent of the orientation of the source movement . In contrast , the classical part of the formula is dependent on the projection of the movement of the source into the line @-@ of @-@ sight which yields different results for different orientations . If ? is the angle between the direction of relative motion and the direction of emission in the observer 's frame (zero angle is directly away from the observer) , the full form for the relativistic Doppler effect becomes :
<formula>