Wavelength and frequency energy relationship

Photon energy is the energy carried by a single photon. The amount of energy is directly proportional to the electromagnetic frequency of the photon and is thus, equivalent, inversely proportional to the wavelength. The higher the frequency of the photon, the higher the energy. Equally, the longer the wavelength of the photon, the lower its energy. Photon energy can be expressed using any unit of energy. Among the devices commonly used to denote photon energy are the electron volts (eV) and joules (as well as its multiples, such as microjoules). As a joule equivalent to 6.24 × 1018 eV, the larger devices may be more useful for denoting energy photons with higher frequency and higher energy, such as gamma rays, as opposed to lower energy photons, such as those in the radio frequency region of the electromagnetic spectrum. Formula Equation for photon energy[1] is E = h c λ {\displaystyle E={\frac {hc}{\lambda }}} Where E is photon energy, h is the Planck constant, c is the speed of light in vacuum and λ is the wavelength of the photon. As h and c are both constants, photon energy E changes in reverse relationship to wavelength λ. To find the photon energy in electron volts, using the wavelength in micrometers, the equation is approximately E / eV = 1,2398 λ / μm {\displaystyle E/{\text{eV}}={\frac {1,2398}{\mathrm {\lambda } /{\text{μm}}}}} Therefore, the photon energy at 1 μm wavelength, the wavelength for near infrared radiation, is approximately 1,2398 ev. Because c λ = f {\displaystyle {\frac {c}{\lambda }}=f} , where f is frequency, the equation for photon energy can be simplified to E = h f {\displaystyle E=hf} This equation is called the Planck-Einstein relationship. Replacing h with its value i J°s and f with its value in hertz gives the photon energy in joules. Therefore, the photon energy at 1 Hz frequency is 6.62606957 × 10−34 joules or 4.135667516 × 10−15 eV. In chemistry and optical engineering, E = h ν {\displaystyle E=h{u }} is used where h is Planck's constant and the Greek letter ν (now) is the frequency of the photon. [2] Example An FM radio station that transmits at 100 MHz emits photons with an energy of about 4.1357 × 10−7 eV. This minimum amount of energy is approximately 8 × 10-13 times the mass of electrons (via mass energy equivalence). Very high-energy gamma rays have photon energies of 100 GeV to 100 TeV (1011 to 1014 electron volts) or 16 nanojoules to 16 microjoules. This corresponds to frequencies of 2,42 × 1025 to 2,42 × 1028 Hz. During photosynthesis, specific chlorophyll molecules absorb photons with red light photons at a wavelength of 700 nm in the photosystem I, corresponding to one energy on each photon of ≈ 2 eV ≈ 3 x 10−19 J ≈ 75 kBT, denoting the thermal energy. A minimum of 48 photons is needed for the synthesis of a single glucose molecule from CO2 and water (chemical potential difference 5 x 10−18 J) with a maximum energy conversion efficiency of 35% See also Photon Electromagnetic radiation Electromagnetic spectrum Planck constant and devices Planck-Einstein relationship Soft photos References ^ Energy of photos. Fotovoltaic Education Network, pveducation.org. Archived from the original on 2016-07-12. Retrieved 2015-06-21. ^ Andrew Liddle (27 April 2015). An introduction to modern cosmology. John Wiley & Sons. p. 16. ISBN 978-1-118-69025-3. Retrieved from Back to Atomic Structure Links Wavelength (l), Frequency (n) and Energy Calculations (E) There are some calculations you can perform that involve waves. Before I go any further, you need to know the constants that are involved.c=3.0 x 108m/s (speed of light in a vacuum)This constant c is how fast electromagnetic radiation (light for all extensive purposes) travels. The second is h, which called Plancks constant.h=6626 x 10-34 J sThis comes from the work of Max Planck preformed in 1900 using blackbody radiation. There were discrete values of energy that differed from this constant. In other words, all energy is a multiple of this constant multiplied by the frequency of the light wave. Energy is therefore quantified, it is always a multiple of a single package of energy. Now on to the equations. Wavelength (l) and Frequency (n) Relationshipsc=ln , where l is wavelength in the meter is frequency in hertz, 1/s or s-1c=3.0 x 108m/s (speed of light in a vacuum)Typical question #1- What is the frequency of red light with a wavelength of 690.nm? (1m=109nm) First-l is wavelength in meters, so convert nm to meter690.nm (1m)=6.90 x 10-7m109nm Now we can rearrange the equation above and solve for frequency, because we already know the constant, c.n=c/ln= 3.0 x 108m/s =4.35 x 1014 s-16.90 x 10-7mTypical question #2- What is the wavelength of light in nm, which has a frequency of 6.6 x 1014 Hz?l=c/= 3 0 x 108m/s =4.55 x 10-7m6.6 x 1014 s-1convert m to nm4.55 x 10-7m(109nm)=455nm1mEnergy (E) and Frequency (n) Ratios- Energy is directly proportional to frequency. To calculate energy from frequency (or vice versa), use the following equationE=hnwhere E is Energy in Joule (J)n is frequency in hertz, 1/s or s-1h=6626 x 10-34 J sTypical Question #1- How much energy does a photon of light have with a frequency of 4.60 x 1014 s-1 ha? E=hnE=(6.626 x 10-34Js)(4.60 x 1014 s-1)E= 3.05 x 10-19JEnergy (E) and Wavelength (l) Relationships- Since energy is calculated from frequency, we can substitute frequency (n) in equation E=hn, using n=c/l, (from c=ln). Now we can do our calculations in one step instead of 2. The new combined equation is:E=hc/lwhere E is Energy in Joule (J) l is wavelength in metersh=6626 x 10-34 J sc=3.0 x 108m/s (speed of light in a vacuum)Typical Question #1- How much energy does a photon of Red light with a wavelength of 690.nm? (1m=109nm) First-l is wavelength in meter, so convert nm to meter690.nm (1m)=6.90 x 10-7m109nm Step 2- Plug this into our new energy equationE=hc/lE=E=(6,626 x 10-34 J s)(3.0 x 108m/s)=2.88 x x 10-7mBack to Atomic Structure LinksChemical Demonstration Videos Science Background: The following information is provided to give the teacher some additional knowledge on the subject of light and color. You can also choose to use this information with students to do research on topics that you see mentioned here, or use the question headers as a form of review for class discussion. This science background is organized to provide information because it relates to each of the lesson's four modules. CATCH THE WAVES: 1. What is the electromagnetic spectrum? The electromagnetic spectrum consists of all the different wavelengths of electromagnetic radiation, including light, radio waves and X-rays. It is a continuum of wavelengths, from zero to infinity. We name regions of the spectrum quite arbitrarily, but the names give us a general sense of the energy; for example, ultraviolet light has shorter wavelengths than radio light. The only region in the entire electromagnetic spectrum to which our eyes are sensitive is the visible region. Gamma rays have the shortest wavelengths, < 0.001 nm (about the size of an atomic nucleus). This is the highest frequency and most energetic region of the electromagnetic spectrum. Gamma rays can result from nuclear reactions that take place in objects such as pulsars, quasars and black holes. X-rays range in wavelength from 0.001 - 10 nm (about the size of an atom). For example, they are generated by overheated gas from exploding stars and quasars, where the temperature is close to one million to ten million degrees. Ultraviolet radiation has wavelengths of 10 - 400 nm (about the size of a virus). Young, hot stars produce a lot of ultraviolet light and bathe interstellar space with this energetic light. Visible light covers the wavelength range from 400 to 700 nm (from the size of a molecule to a protozoan). Our sun emits most of its radiation in the visible area, which our eyes perceive as the colors of the rainbow. Our eyes are sensitive only to this small part of the electromagnetic spectrum. Infrared wavelengths range from 700 nm - 1 mm (from the width of a pinpoint to the size of small plant seeds). At a temperature of 37 degrees C, our bodies radiate at a peak intensity close to 900 nm. Radio waves are longer than 1 mm. Since these are the longest waves, they have the lowest energy and are associated with the lowest temperatures. Radio wavelengths are everywhere: in the background radiation of the universe, in interstellar clouds, and in the cool remnants of supernova explosions, to name a few. Radio stations use radio wavelengths of electromagnetic radiation to send signals that our radios then translate into sound. These wavelengths are usually a few meters long in the FM band and up to 300 meters or more in the AM band. Radio stations transmit electromagnetic radiation, not sound. The radio station encodes a pattern on the electromagnetic radiation broadcast, and then our radios get it the radiation, decode the pattern and translate the pattern into sound. New instrumentation and computer technologies from the late 20th century allow scientists to measure the universe in many regions of the electromagnetic spectrum. We build devices that are sensitive to light that our eyes can't see. Then, so that we can see these regions of the electromagnetic spectrum, computer imaging techniques assign arbitrary color values to the light. MAKING WAVES: 1. What is a light wave? Light is a disturbance of electrical and magnetic fields that travel in the form of a wave. Imagine throwing a rock into a still pond and watching round ripples move outwards. Like these ripples, each light wave has a series of high points called cams, where the electric field is highest, and a series of low points called valleys, where the electric field is lowest. The wavelength is the distance between two wave chambers, which is the same as the distance between two troughs.. The number of waves passing through a given point in a second is called the frequency, measured in units of cycles per second called Hertz. The speed of the scale is therefore equal to the frequency times the wavelength. 2. What is the ratio of frequency to wavelength? Wavelength and frequency of light are closely related. The higher the frequency, the shorter the wavelength. Because all light waves move through a vacuum at the same speed, the number of wave cams passing a certain point in one second depends on the wavelength. This number, also known as the frequency, will be larger for a short wavelength wave than for a long wavelength wave. The equation that relates wavelength and frequency is: For electromagnetic radiation, the speed is equal to the speed of light, c, and the equation becomes: 3. What is the ratio of wavelength, frequency and energy? The energy of a wave is directly proportional to its frequency, but inversely proportional to its wavelength. In other words, the greater the energy, the greater the frequency and shorter (smaller) wavelength. Given the relationship between wavelength and frequency described above, it follows that short wavelengths are more energetic than long wavelengths. HEATING UP: 1. How is wavelength and temperature related? All objects emit electromagnetic radiation, and the amount of radiation emitted at each wavelength determines the temperature of the object. Hot objects emit more of their light at short wavelengths, and cold objects emit more of their light at long wavelengths. The radiation temperature of an object is related to the wavelength at which the object emits the most light. We call the amount of light emitted at a certain wavelength, the intensity. When you draw the intensity of light from an object at each wavelength, you track out a smooth curve called a blackbody curve. For any temperature, the black body curve shows how much energy (intensity) is radiated at each wavelength, the wavelength where the intensity peaks determine the color of that object. The intensity stops will be at shorter (bluer) wavelengths for warmer objects, and at longer (redder) wavelengths for cooler objects. Therefore, you can tell the temperature of a star or galaxy by its color because color is closely related to the wavelength at which its light intensity peaks. Blackbody curves, for objects of all temperatures, have a similar shape, as shown in the graphernabelow. However, the top of the curve of a warmer object will be larger (more intense) than will top the curve for a cooler object. For example, the intensity difference between the peak of the curve of an object at 30,000 K and the peak of the curve of an object at 300 K (body temperature) is a factor of 10 billion. This means that a star of 30,000 K spends more energy at a factor of 10 billion than a human at body temperature. Due to the large intensity difference, it would be difficult to show both of these curves on the graph below without using logaritmer. To draw blackbody curves with large intensity differences on the heating up side of Amazing Space's Star Light, Star Bright, we have made the scale of the intensity axis adjust for each temperature change. 2. How are temperature and color related? The amount of light produced by an object at each wavelength depends on the temperature of the object that produces the light. Stars warmer than the Sun (over 6000 degrees C) turn off most of their light in the blue and ultraviolet regions of the spectrum. Stars cooler than the Sun (below 5,000 degrees C) put out most of their light in the red and infrared regions of the spectrum. Solid objects that heat up to 1,000 degrees C appear red but lay out much more (invisible) infrared light than red light. STELLAR ENCOUNTERS: 1. How can light teach us information about the stars? Electromagnetic radiation, or light, is a form of energy. Visible light is a narrow range of wavelengths of the electromagnetic spectrum. By measuring the wavelength or frequency of light coming from objects in the universe, we can learn something about their nature. Since we are not able to travel to a star or take samples from a galaxy, we must rely on electromagnetic radiation to carry information to us from distant objects in space. The human eye is sensitive to a very small range of wavelengths called visible light. But most objects in the universe radiate at wavelengths that our eyes cannot see. Astronomers use telescopes with detection devices that are sensitive to wavelengths other than visible light; This allows astronomers to study objects that emit this radiation, otherwise invisible to us. Computer technicians then encode the light in arbitrary colors that we CAN see. The Hubble Space Telescope can measure wavelengths from about 0.1150 to 2 microns, an area that covers more than just visible light. These measurements of electromagnetic radiation allow to determine certain physical characteristics of objects, such as their temperature, composition, and speed. Words from the scientist: Every day when the sun goes down, the sky puts on a beautiful show of stars. It's natural to ask, how far are these stars? Are they moving? What are they made of? Are they all the same? Since must of us cannot physically go to the stars to learn about them, we depend on the light we receive from these distant objects to study them. In my everyday work, I look at ultraviolet radiation from the centers of galaxies to study the physical and kinematic properties of the gas that radiates this energy. Anuradha Koratkar. References: Henbest , Nigel and Michael Marten, The New Astronomy Second Edition , Cambridge University Press, 1996. This book provides an explanation of images in all wavelengths as well as thorough information regarding electromagnetic radiation. Kuhn , Karl F. , Pursuit of the Universe, Western Publishers, 1991. Chapter 4 provides background information on light and the electromagnetic spectrum, including mathematical formulas for determining wavelength, Doppler shift, Weins law, etc. Space-based astronomy, NASA, 1994. Griffith, Mary, The Homeschooling Handbook, Prima Publishing, CA, 1997. A book of information and resources for homeschoolers. Send your comments about this page to: amazing-space@stsci.edu amazing-space@stsci.edu