

# “Let there be light...”

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THE CAUSES OF ELECTROMAGNETIC RADIATION

# Learning Target

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I can construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

This is the goal for what you should be able to do if you are meeting the requirements of this class.

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# Types of Electromagnetic Radiation

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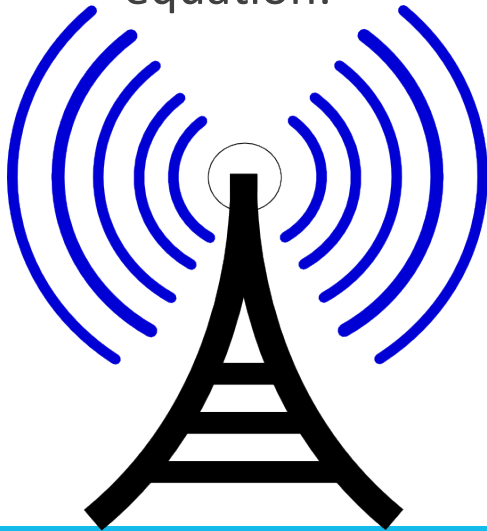
# Types of Electromagnetic Radiation

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Electromagnetic waves can be characterized by their wavelength or frequency and classified into different types of radiation.

The longest wavelengths are called radio waves, followed by microwaves, infrared, visible light, ultraviolet, x rays, and gamma rays.

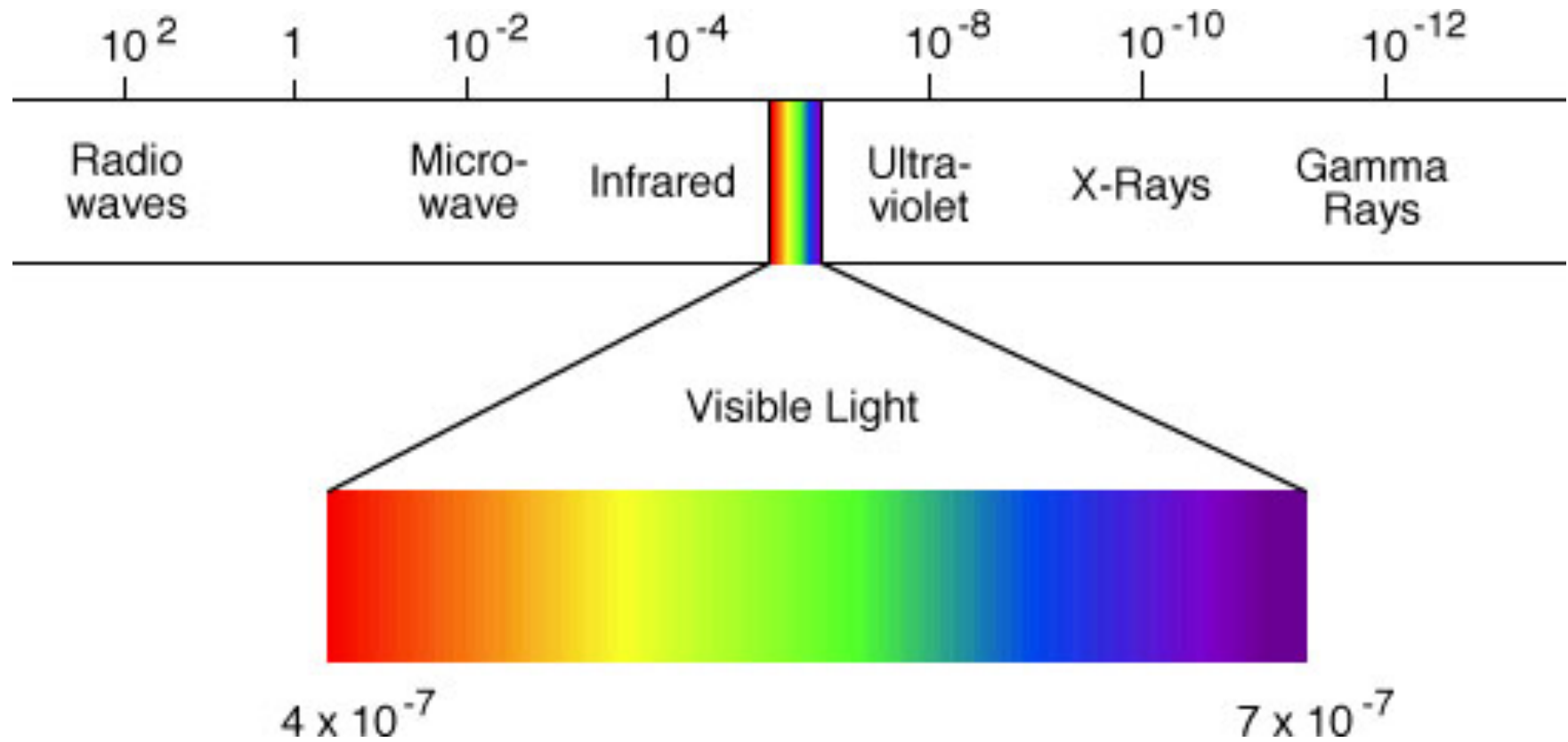
The wavelength of light is related to its frequency by the wave equation:



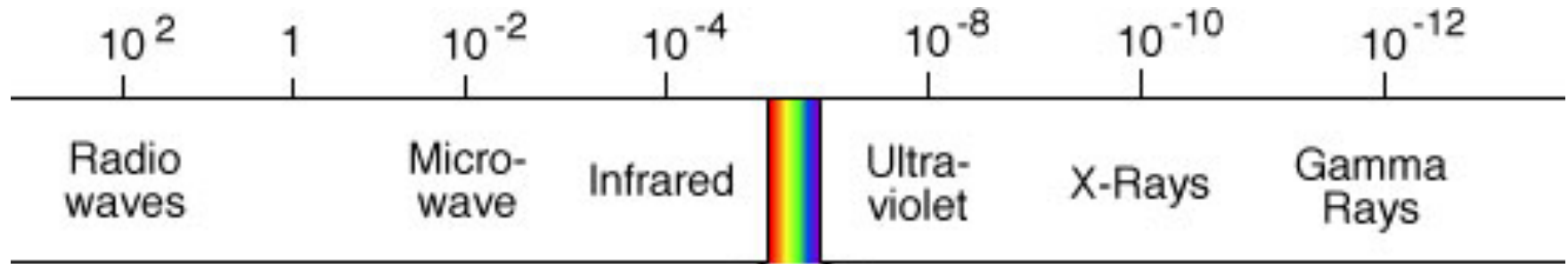
$$v = f \lambda$$



Approximate wavelength in meters:



Approximate wavelength in meters:



Visible Light



$4 \times 10^{-7}$

$7 \times 10^{-7}$

**LONG**  
Wavelength

**LOW**  
Frequency

**SHORT**  
Wavelength

**HIGH**  
Frequency



**Table 1 – Electromagnetic spectrum**

		Wavelength		
Radio waves		Above		0.3 m
Microwave		0.3 m	to	1 mm
Infrared		1 mm	to	789 nm
Visible	Red	789 nm	to	625 nm
	Orange	625 nm	to	600 nm
	Yellow	600 nm	to	577 nm
	Green	577 nm	to	491 nm
	Blue	491 nm	to	455 nm
	Violet	455 nm	to	390 nm
Ultraviolet		390 nm	to	8.82 nm
X ray		8.82 nm	to	6 pm
Gamma ray		Less than		6 pm

# Frequency-Energy Relationship

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The energy of the radiation is related to the frequency of the light wave:

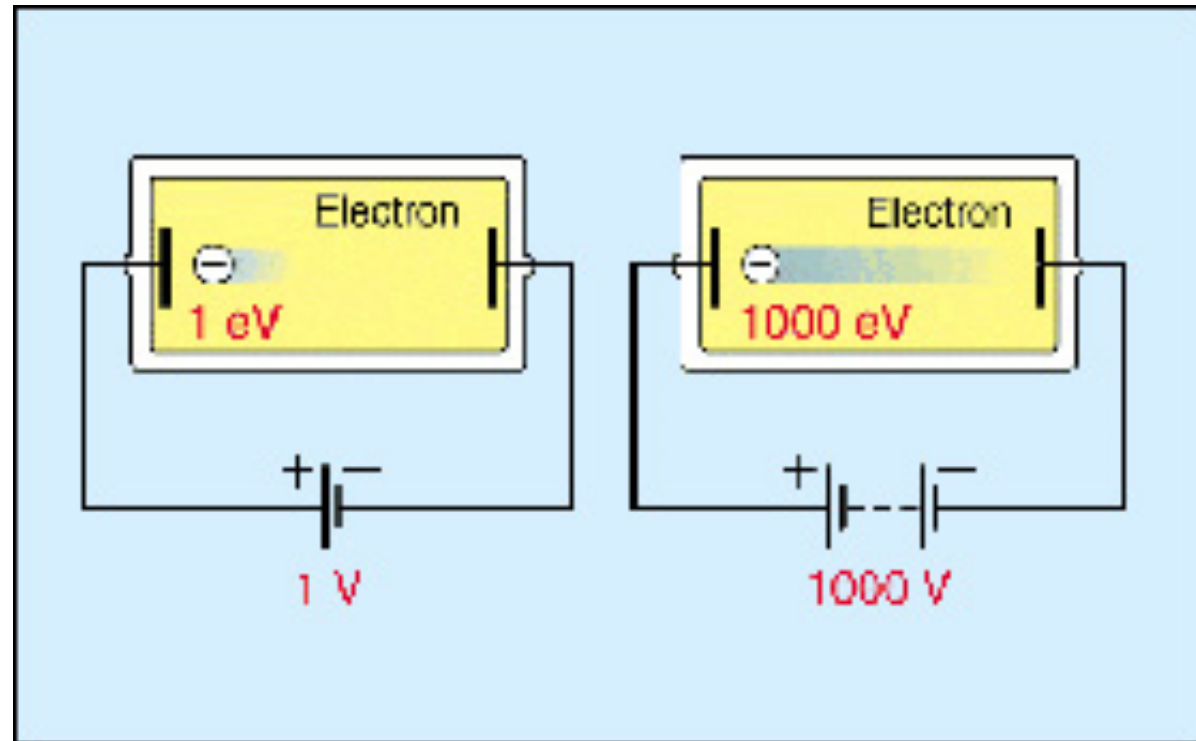
$$E = hf \quad \text{or} \quad E = \frac{hc}{\lambda}$$

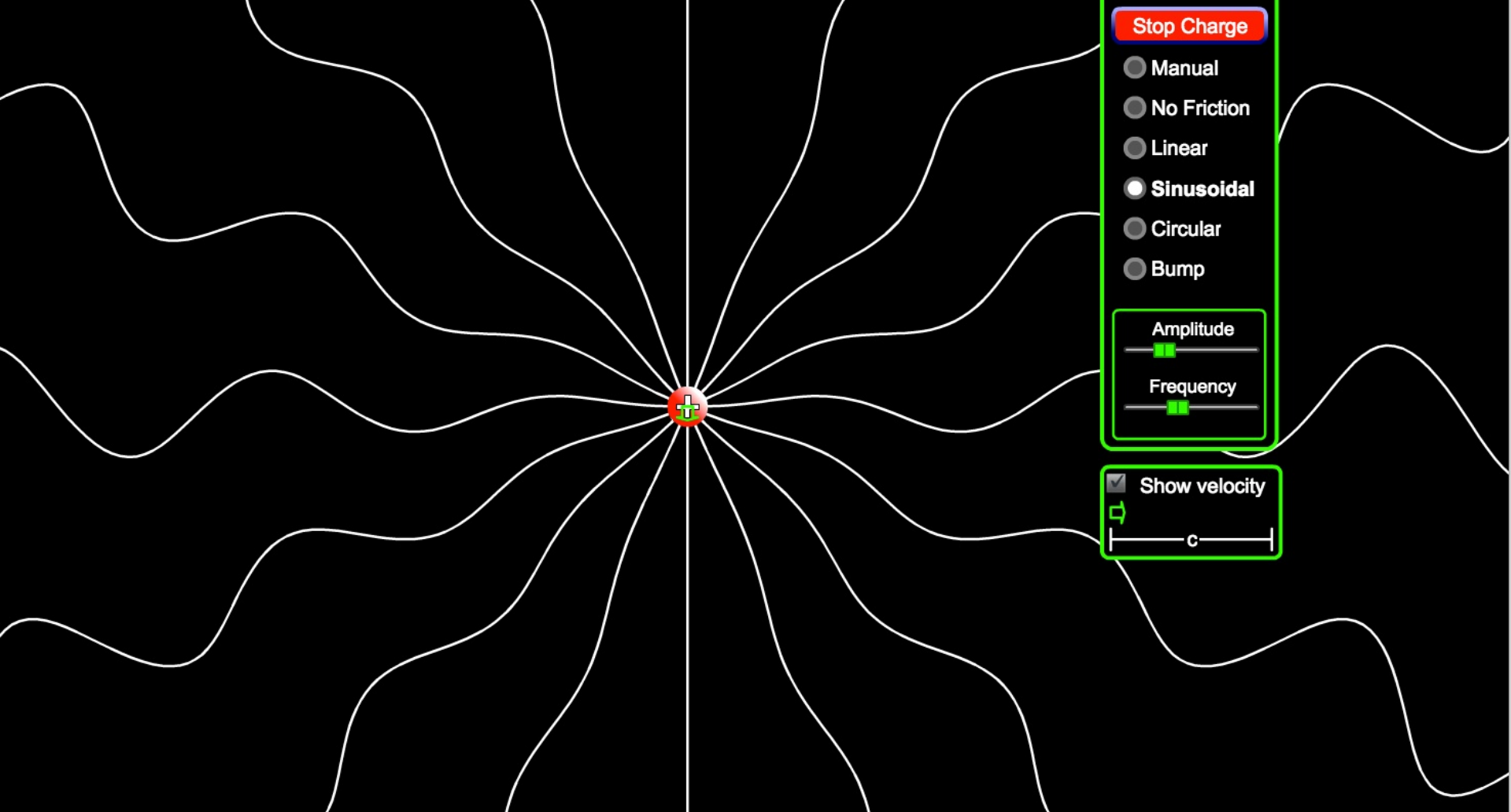
The constant ***h*** is known as the Planck constant, and it is equal to:

$$\mathbf{h = 4.14 \times 10^{-15} \, eV \cdot s}$$

What is an  
“electron-volt?”

An **electron volt** is the energy required to accelerate an electron across an electric potential difference of 1 volt.





# Simulation: Acceleration of a Charged Particle; Frequency, Wavelength, and Speed

<http://phet.colorado.edu/en/simulation/radiating-charge>

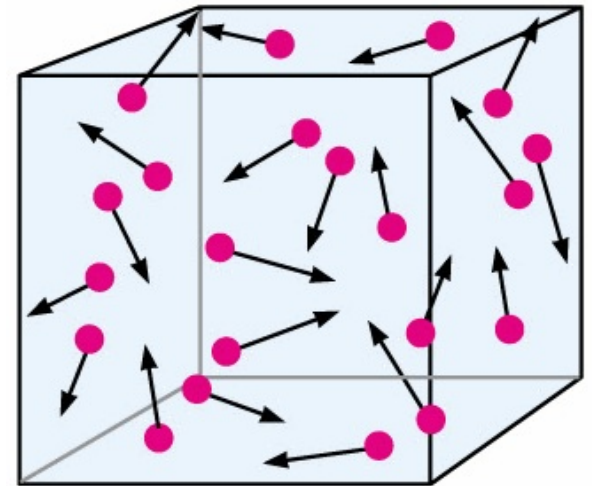
# Thermal Radiation

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Electromagnetic radiation that is generated by the motion of charged particles in matter is known as **thermal radiation**.

The average kinetic energy of the particles in an object or system at a given time is defined as its **temperature**.

All matter with a temperature above absolute zero emits thermal radiation.





# Thermal Radiation Curve

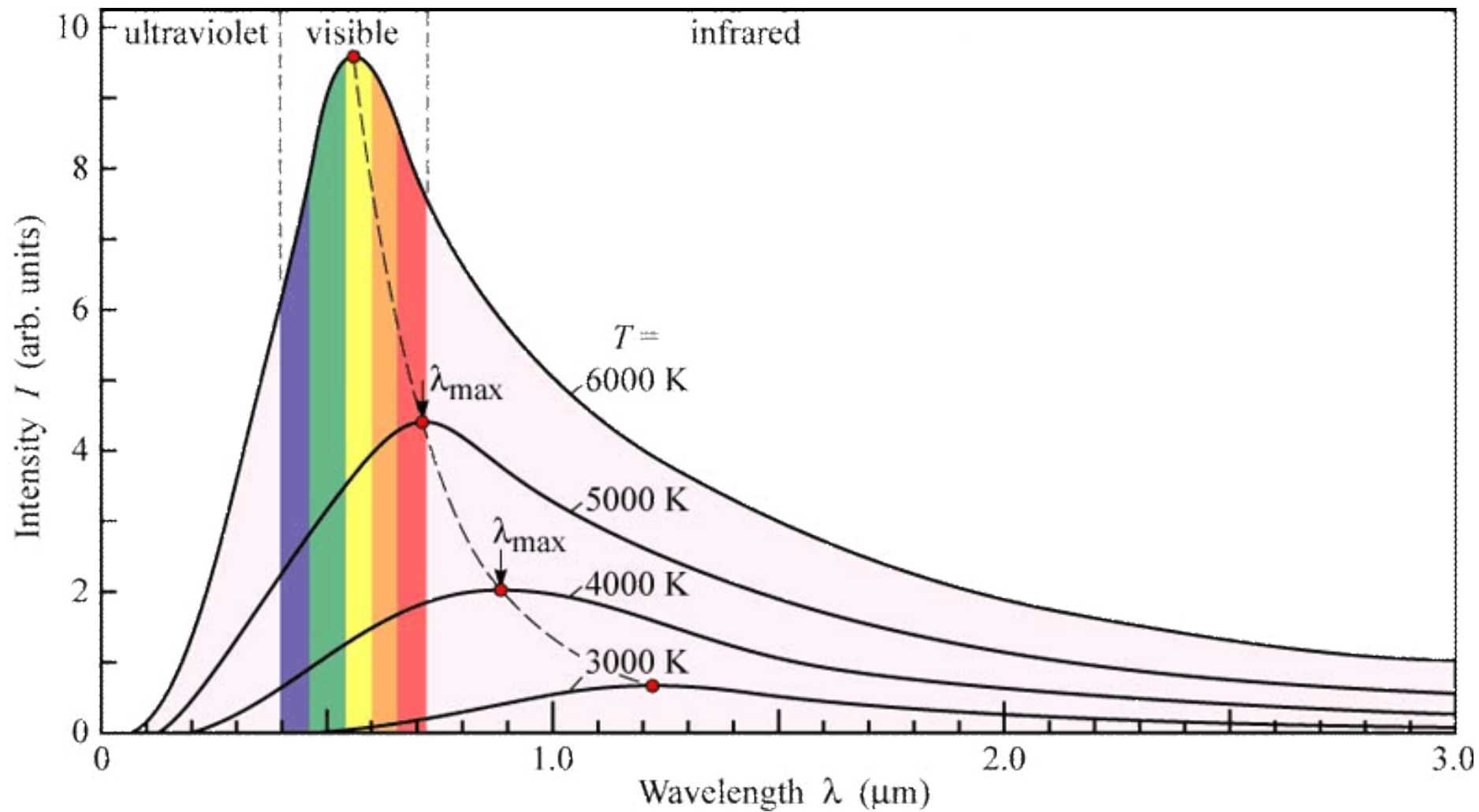
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Thermal radiation consists of a wide range of wavelengths—due to a wide spectrum of energies even at a single temperature.

- A few atoms move very fast—short wavelength radiation.
- A few atoms move very slow—long wavelength radiation.
- The majority of atoms move at a speed that depends on the temperature of the object.

For different temperatures, an object will emit thermal radiation that peaks at different wavelengths.

- Hotter objects emit most of their radiation at shorter wavelengths.
- Cooler objects emit most of their radiation at longer wavelengths.





# Wavelength of Maximum Intensity

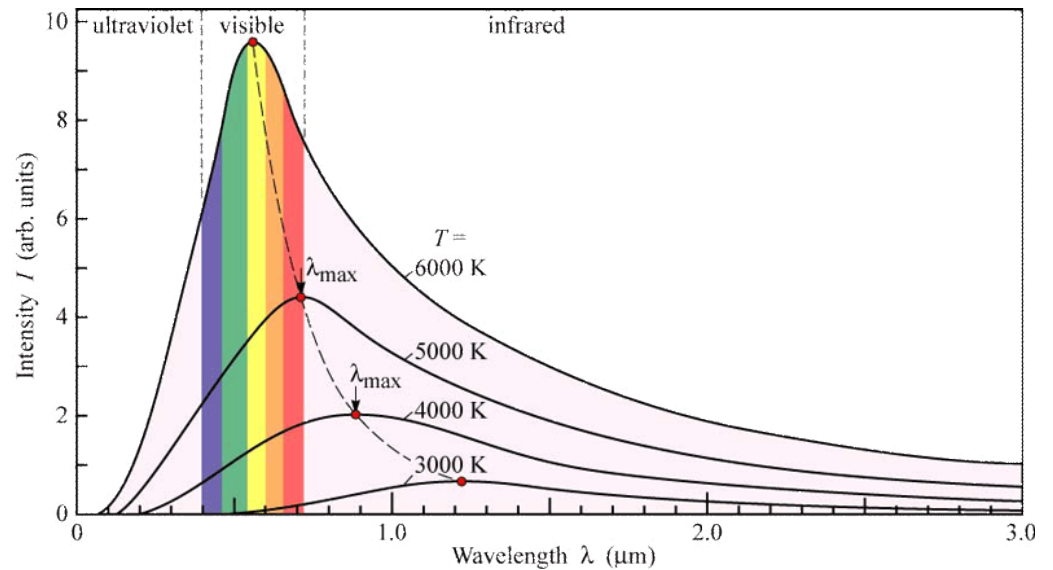
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The wavelength of maximum intensity is inversely proportional to the temperature of the object measured in Kelvins (K):

$$\lambda_{\max} = \frac{2.898 \times 10^{-3} \text{ m} \cdot \text{K}}{T}$$

# Simulation: Thermal Radiation Curve

<http://phet.colorado.edu/en/simulation/blackbody-spectrum>



**Example 1:** A typical human being has an internal temperature of 98.6 degrees Fahrenheit (310 K). What wavelength of radiation does a typical human being give off most at this temperature? What type of electromagnetic radiation is this?

**Example 2:** The Sun appears to give off radiation with a wavelength of maximum intensity at 508 nm. What is the temperature of the Sun's surface?

# Periodic Table of the Elements

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1A												8A																							
1 H Hydrogen 1.008	2 He Helium 4.003																																		
3 Li Lithium 6.941		4 Be Beryllium 9.012												5 B Boron 10.811		6 C Carbon 12.011		7 N Nitrogen 14.007		8 O Oxygen 15.999		9 F Fluorine 18.998		10 Ne Neon 20.180											
11 Na Sodium 22.990		12 Mg Magnesium 24.305												13 Al Aluminum 26.982		14 Si Silicon 28.086		15 P Phosphorus 30.974		16 S Sulfur 32.066		17 Cl Chlorine 35.453		18 Ar Argon 39.948											
19 K Potassium 39.098		20 Ca Calcium 40.078		21 Sc Scandium 44.956		22 Ti Titanium 47.88		23 V Vanadium 50.942		24 Cr Chromium 51.996		25 Mn Manganese 54.938		26 Fe Iron 55.933		27 Co Cobalt 58.933		28 Ni Nickel 58.693		29 Cu Copper 63.546		30 Zn Zinc 65.39		31 Ga Gallium 69.732		32 Ge Germanium 72.61		33 As Arsenic 74.922		34 Se Selenium 78.09		35 Br Bromine 79.904		36 Kr Krypton 84.80	
37 Rb Rubidium 84.468		38 Sr Strontium 87.62		39 Y Yttrium 88.906		40 Zr Zirconium 91.224		41 Nb Niobium 92.906		42 Mo Molybdenum 95.94		43 Tc Technetium 98.907		44 Ru Ruthenium 101.07		45 Rh Rhodium 102.906		46 Pd Palladium 106.42		47 Ag Silver 107.868		48 Cd Cadmium 112.411		49 In Indium 114.818		50 Sn Tin 118.71		51 Sb Antimony 121.760		52 Te Tellurium 127.6		53 I Iodine 126.904		54 Xe Xenon 131.29	
55 Cs Cesium 132.905		56 Ba Barium 137.327		57-71		72 Hf Hafnium 178.49		73 Ta Tantalum 180.948		74 W Tungsten 183.85		75 Re Rhenium 186.207		76 Os Osmium 190.23		77 Ir Iridium 192.22		78 Pt Platinum 195.08		79 Au Gold 196.967		80 Hg Mercury 200.59		81 Tl Thallium 204.383		82 Pb Lead 207.2		83 Bi Bismuth 208.980		84 Po Polonium [208.982]		85 At Astatine 209.987		86 Rn Radon 222.018	
87 Fr Francium 223.020		88 Ra Radium 226.025		89-103		104 Rf Rutherfordium [261]		105 Db Dubnium [262]		106 Sg Seaborgium [266]		107 Bh Bohrium [264]		108 Hs Hassium [269]		109 Mt Meitnerium [268]		110 Ds Darmstadtium [269]		111 Rg Roentgenium [272]		112 Cn Copernicium [277]		113 Uut Ununtrium unknown		114 Fl Flerovium [289]		115 Uup Ununpentium unknown		116 Lv Livermorium [298]		117 Uus Ununseptium unknown		118 Uuo Ununoctium unknown	

Lanthanide Series	57 <b>La</b> Lanthanum 138.906	58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.908	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium 144.913	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.966	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.925	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.930	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.934	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967
Actinide Series	89 <b>Ac</b> Actinium 227.028	90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.036	92 <b>U</b> Uranium 238.029	93 <b>Np</b> Neptunium 237.048	94 <b>Pu</b> Plutonium 244.064	95 <b>Am</b> Americium 243.061	96 <b>Cm</b> Curium 247.070	97 <b>Bk</b> Berkelium 247.070	98 <b>Cf</b> Californium 251.080	99 <b>Es</b> Einsteinium [254]	100 <b>Fm</b> Fermium 257.095	101 <b>Md</b> Mendelevium 258.1	102 <b>No</b> Nobelium 259.101	103 <b>Lr</b> Lawrencium [262]

Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide
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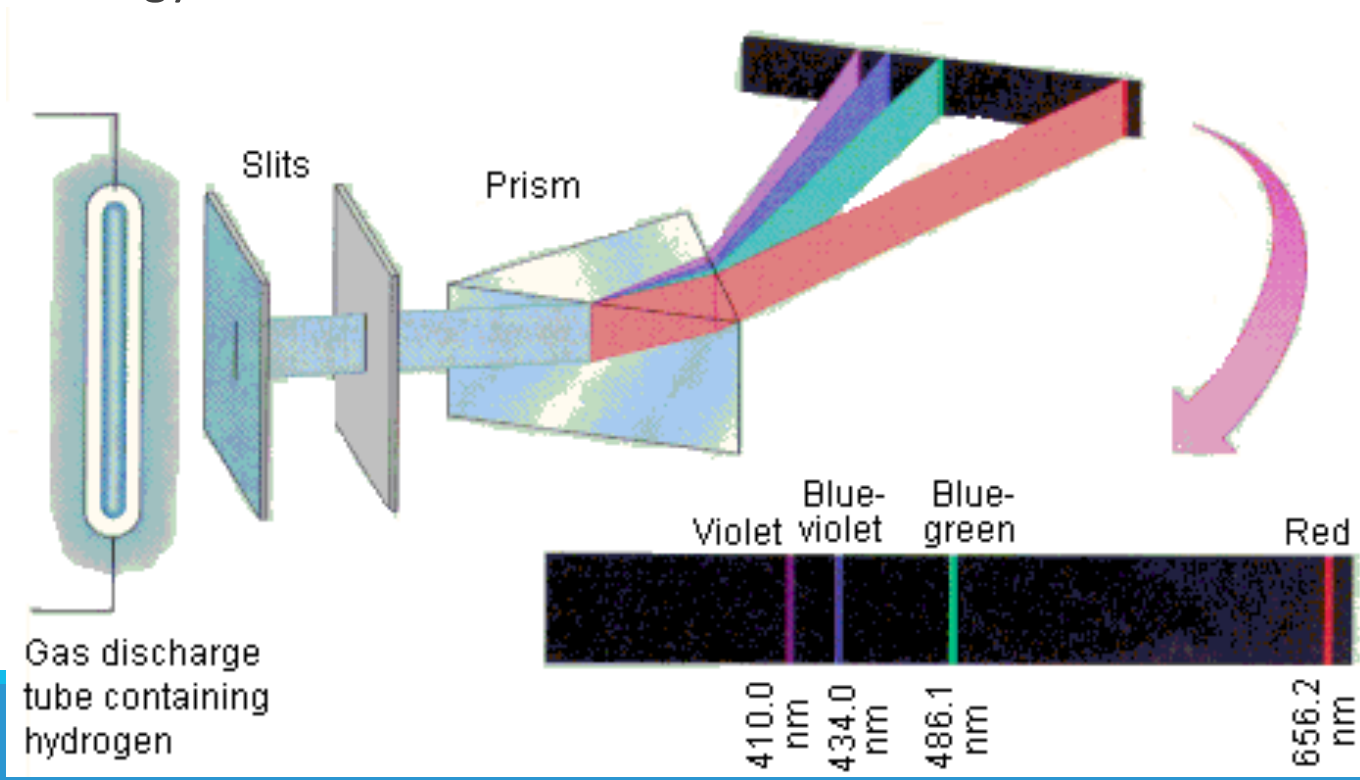
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sciencenotes.org

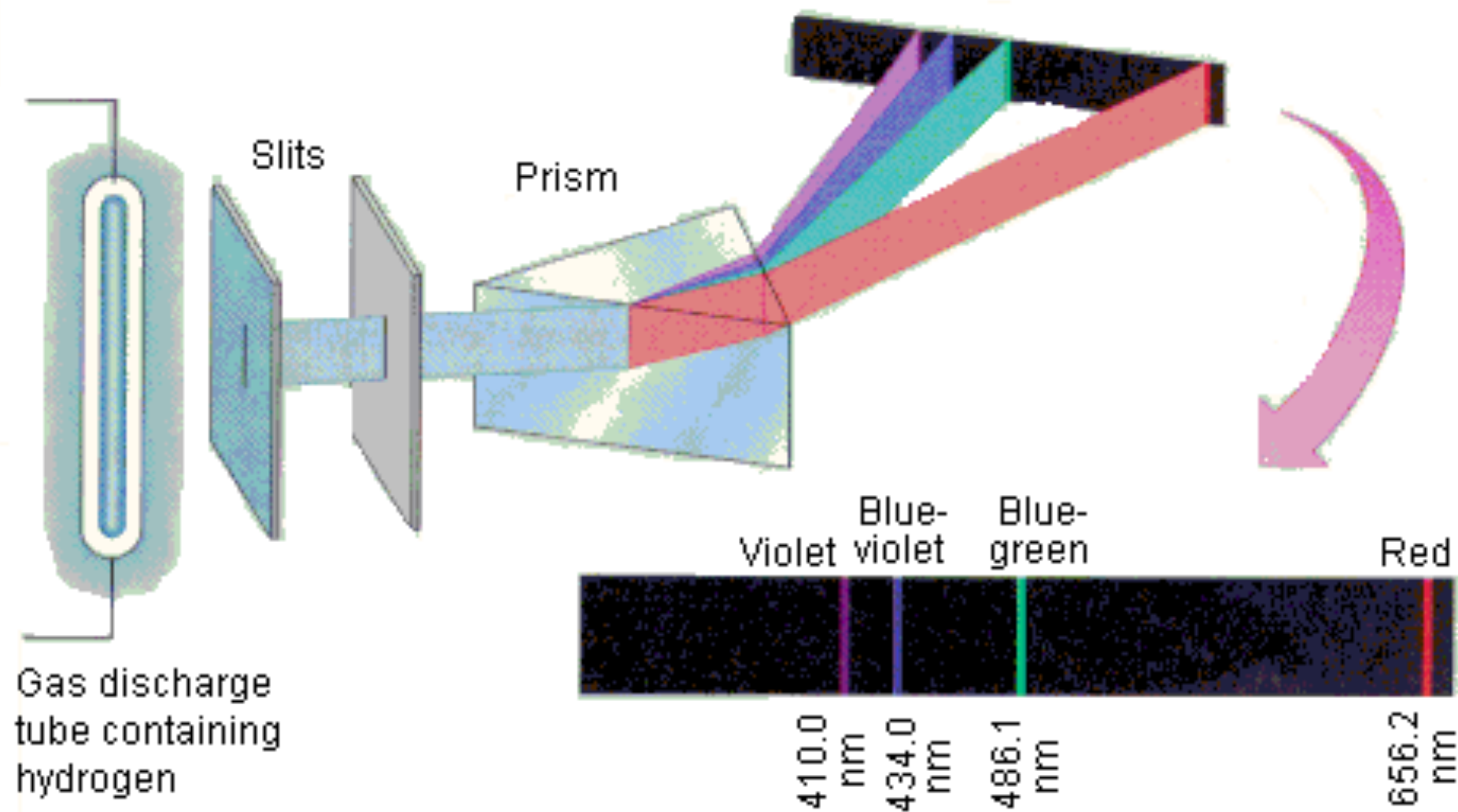
## Light from Neon Gas

# Observation of Light with Specific Wavelengths

If a low-density gas is given energy, it will also produce light—but in a different way.

Each element has specific wavelengths of light that it emits after being given energy.





# The Bohr Model of an Atom

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The Bohr model of the atom explains this phenomenon.

The Bohr model predicts that the electrons in atoms are in orbits of differing energy (called “energy levels”) around the nucleus.

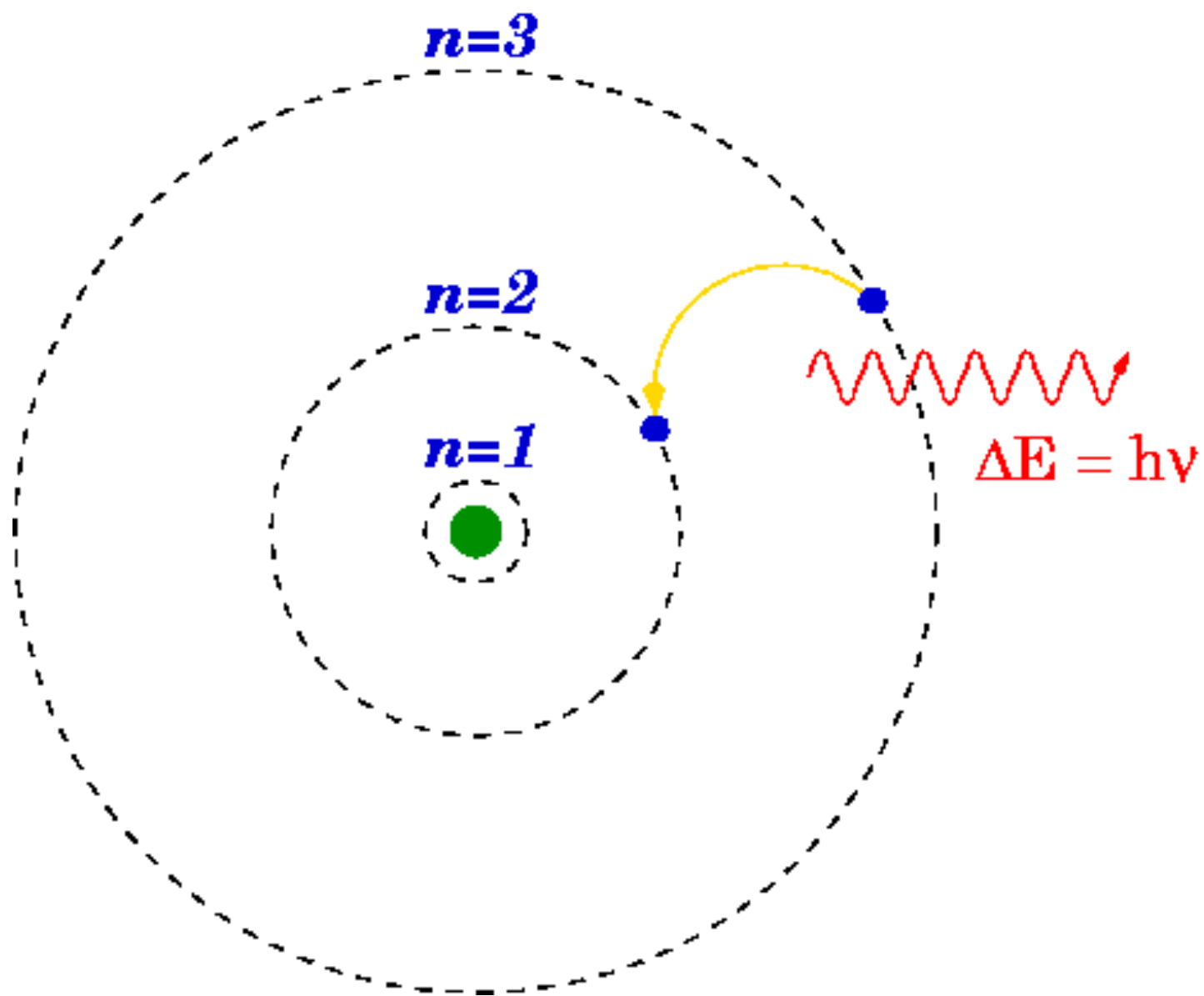
The electron can be in one energy level or another but nothing in between.

The electron normally occupies the lowest energy level—or the **ground state**—but it can be “excited” to a higher energy level.

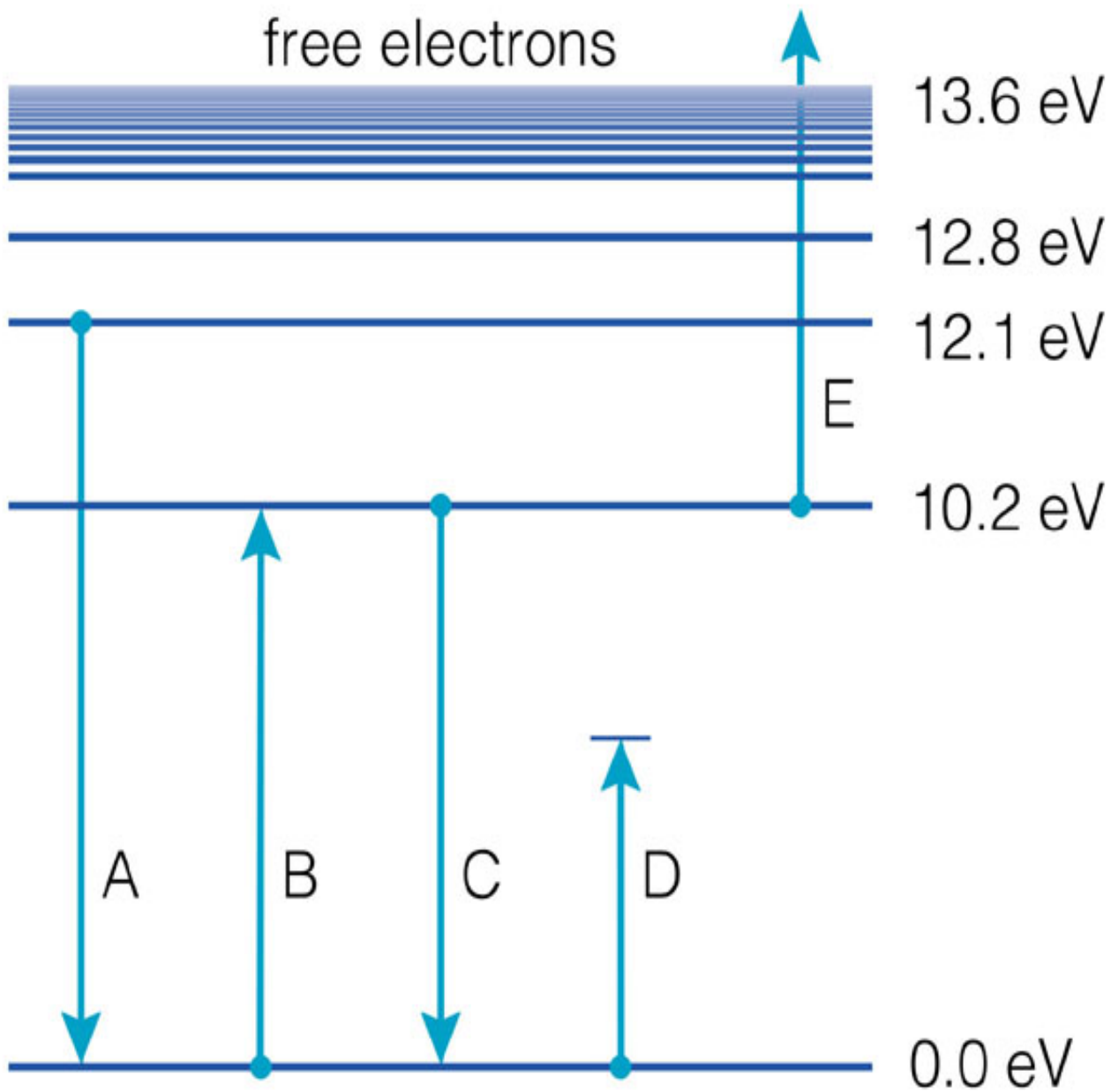
After being excited, the electron can return to its original ground state by releasing the energy it absorbed.

The energy is released as a photon of electromagnetic radiation, and the amount of energy is equal to the difference in the energy levels.





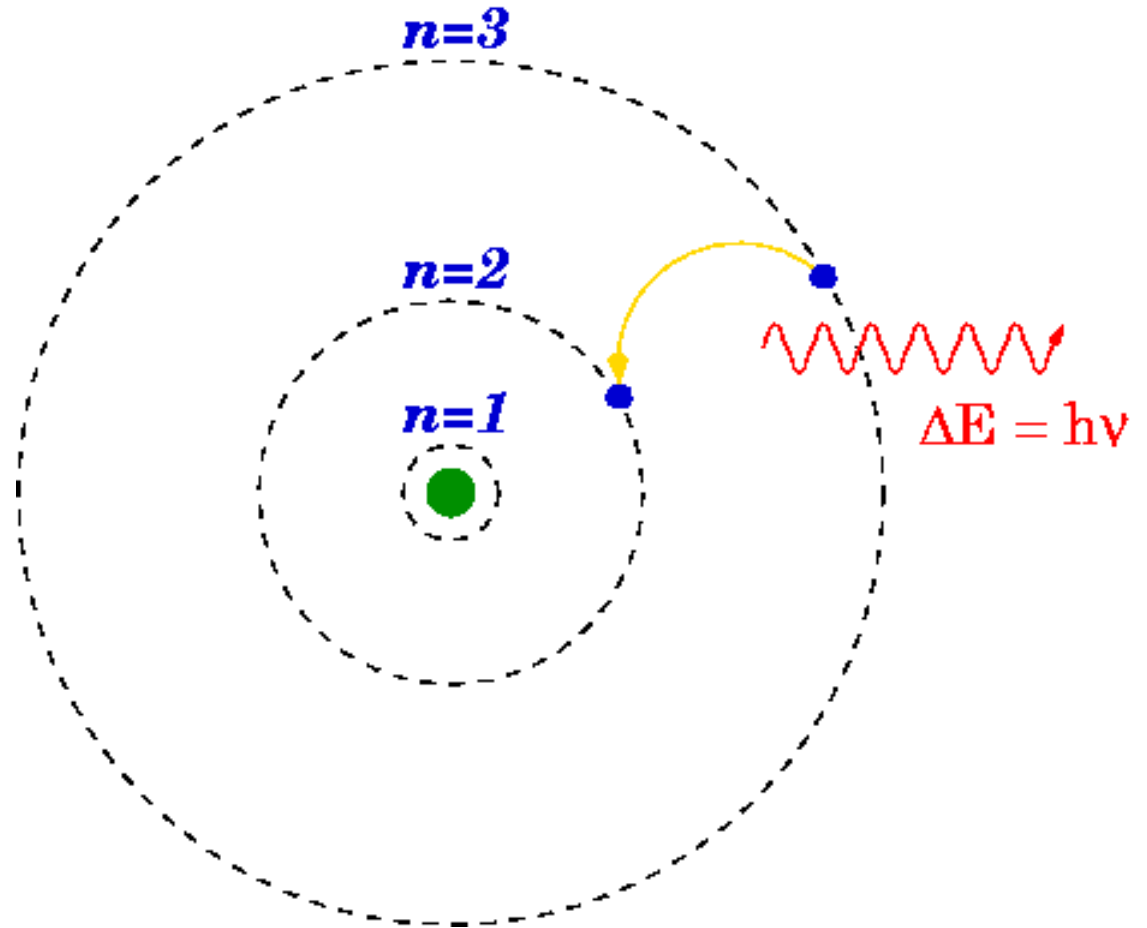
free electrons



**Example 3:** An electron falls from the third energy level of 12.5 eV to the second energy level of 10.5 eV. What is the energy of the photon emitted? What is the wavelength of this photon? What type of electromagnetic radiation is this?

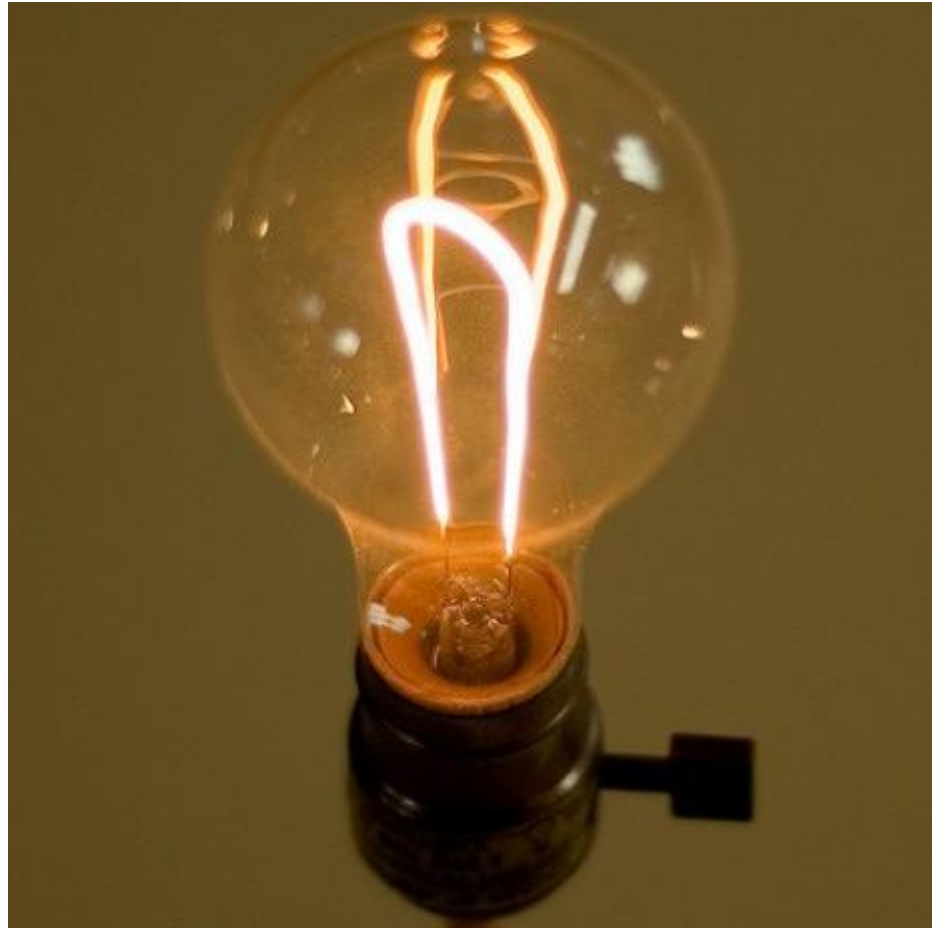
# Simulation: Bohr Model of an Atom

<https://phet.colorado.edu/en/simulation/hydrogen-atom>



# What causes light?

[https://youtu.be/  
oCEKMEeZXug](https://youtu.be/oCEKMEeZXug)



# Simulation: Neon Discharge Tube

[http://phet.colorado.edu/  
en/simulation/discharge-  
lamps](http://phet.colorado.edu/en/simulation/discharge-lamps)



# Make A Spectrum

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Hydrogen



Sodium



Helium



Neon



Mercury

# Observations of the Universe

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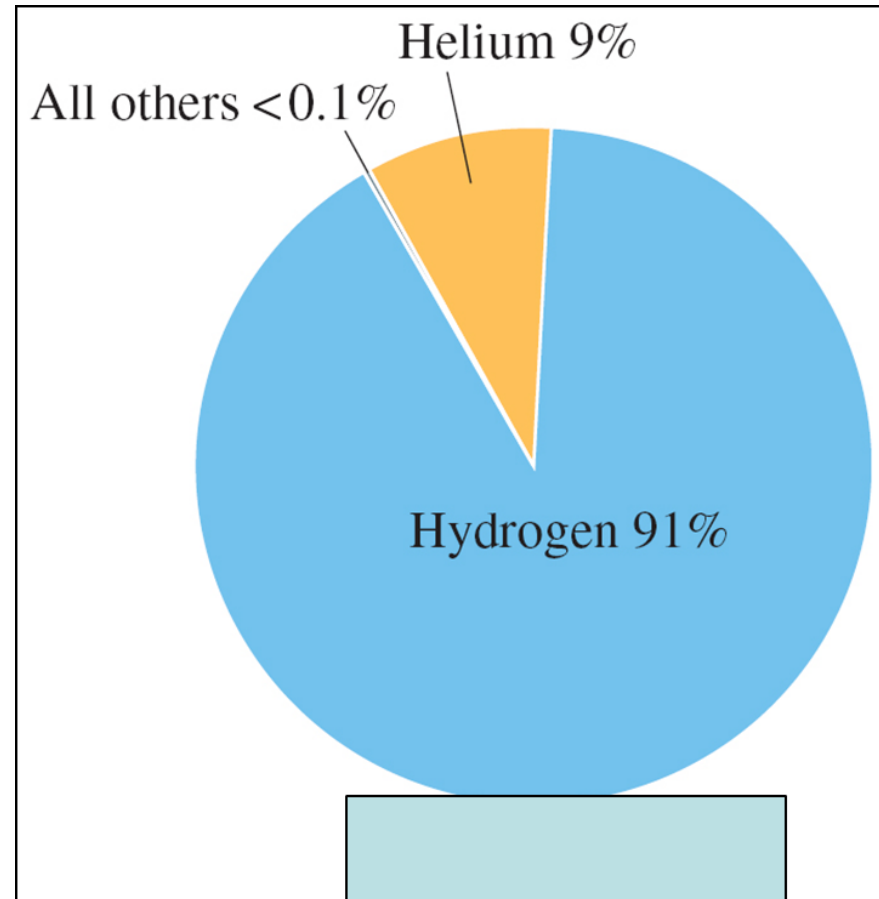


# Cosmic Abundance of Elements

Astronomers look at the Sun's radiation and they find that it is made mostly of hydrogen, some helium, and traces of other gases.

Based on the light from stars and galaxies, the universe appears to be made of approximately 91% Hydrogen, 9% Helium, and less than 0.1% other elements.

*A theory of the origin of the universe must account for this abundance of hydrogen and helium.*



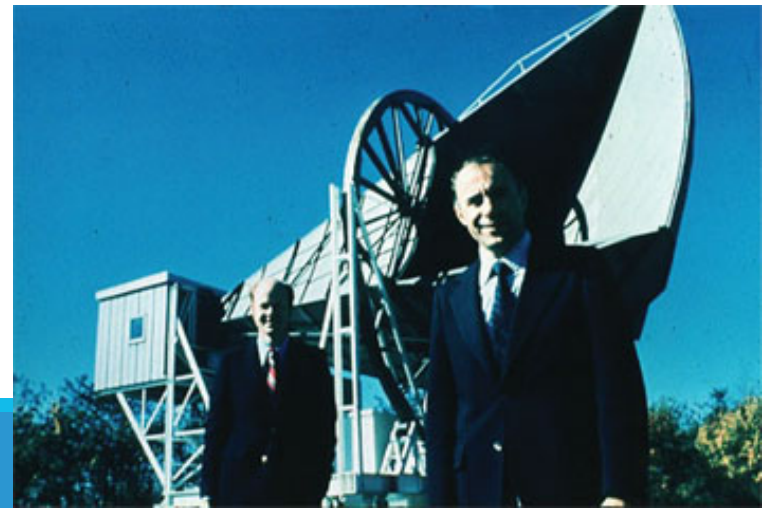
# Cosmic Microwave Background

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In 1964, while attempting to detect faint radio waves bounced off balloon satellites, Arno Penzias and Robert Wilson kept getting interference (like static) in their receiver.

After attempting to get rid of all possible sources of interference—including removing bird droppings—they determined that the radio noise was coming from space, and in all directions.

The radiation they were detecting looked like a thermal radiation curve with a peak wavelength of 1.07 mm. ***What does this imply about the temperature of the universe?***



# Cosmic Microwave Background

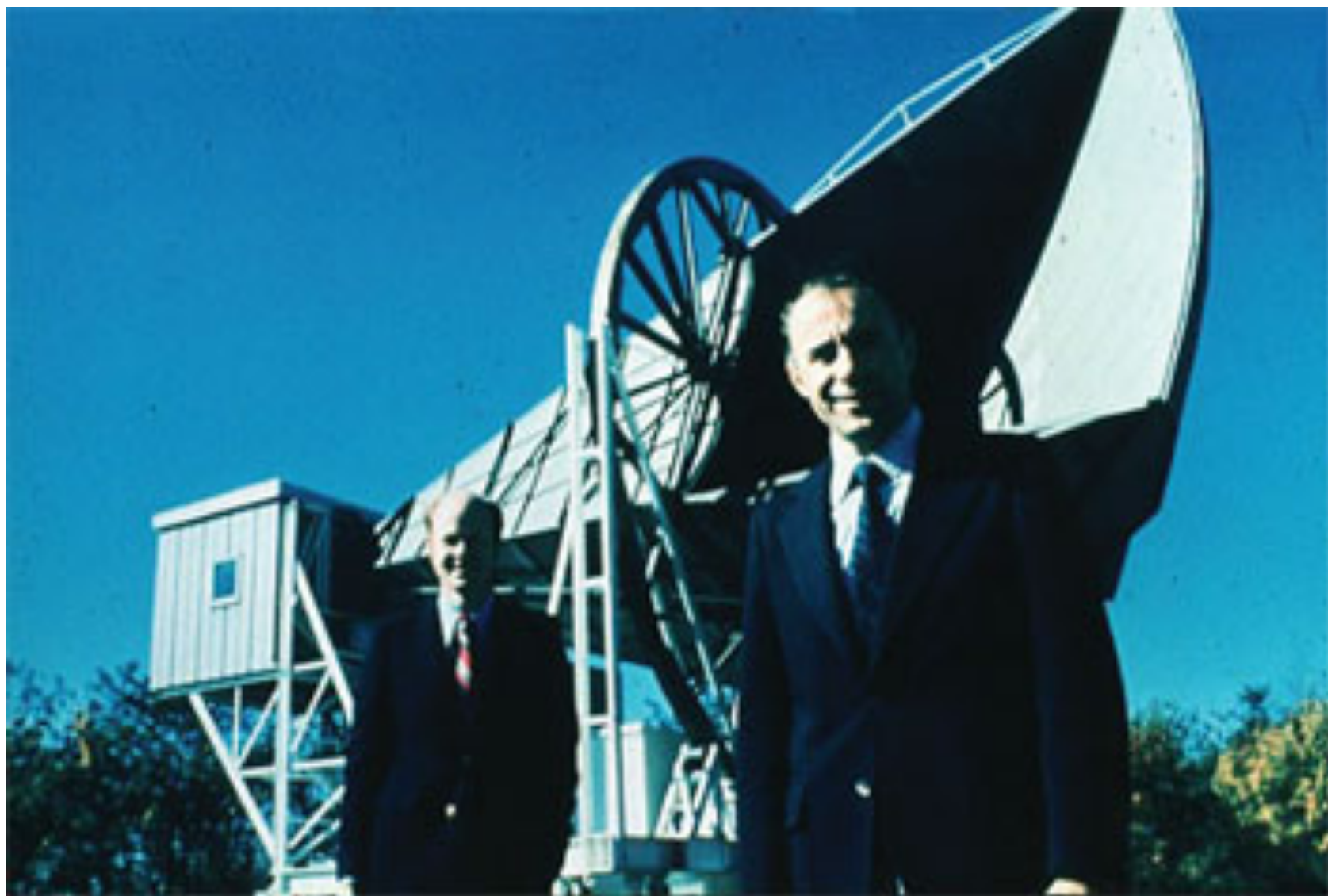
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***The universe has a temperature of 2.7 K. Any theory of the universe's origins must account for this fact also.***



# Practice

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