“Let there be light…”

THE CAUSES OF ELECTROMAGNETIC RADIATION

Learning Target

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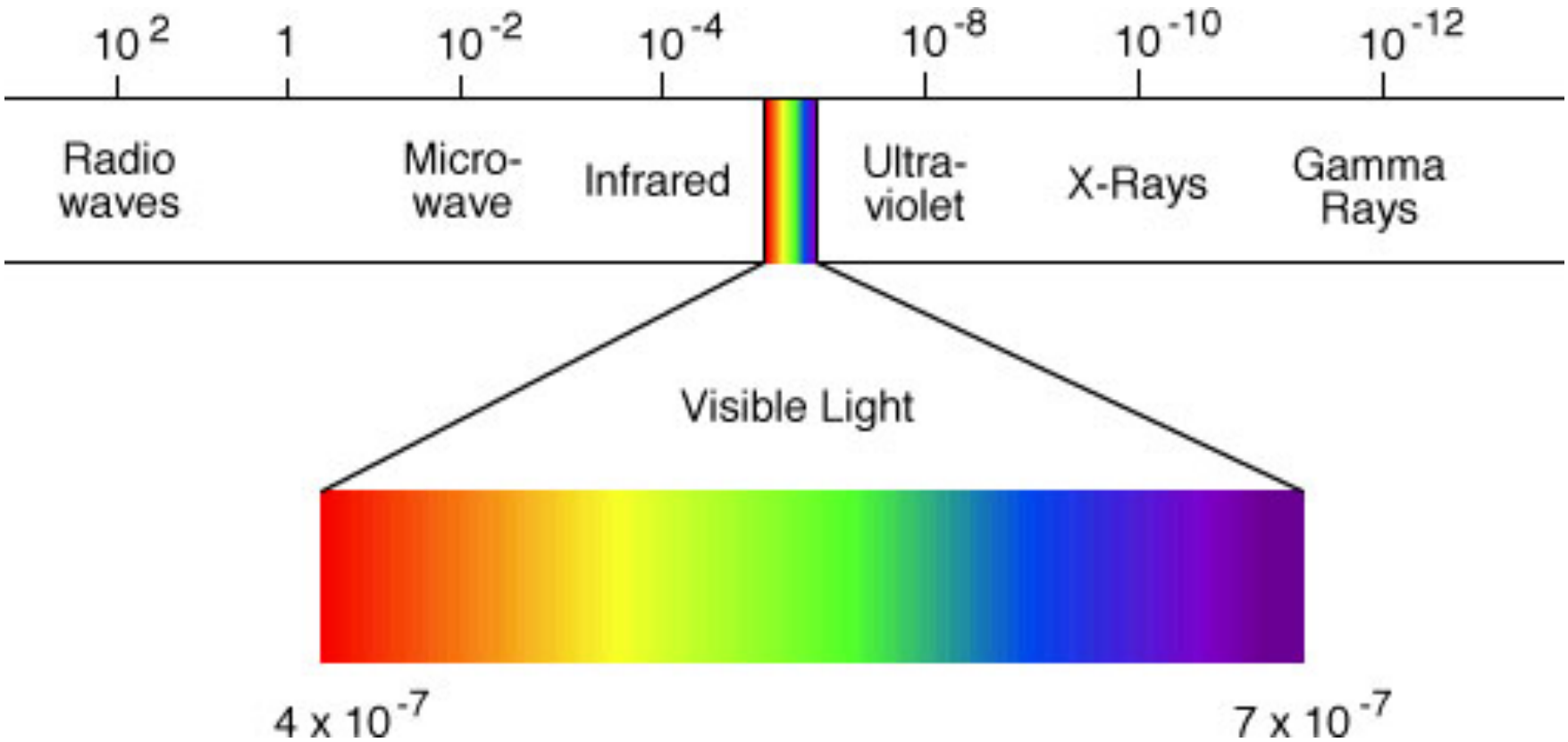
Electromagnetic waves can be characterized by their wavelength or frequency and classified into different types of radiation.

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:



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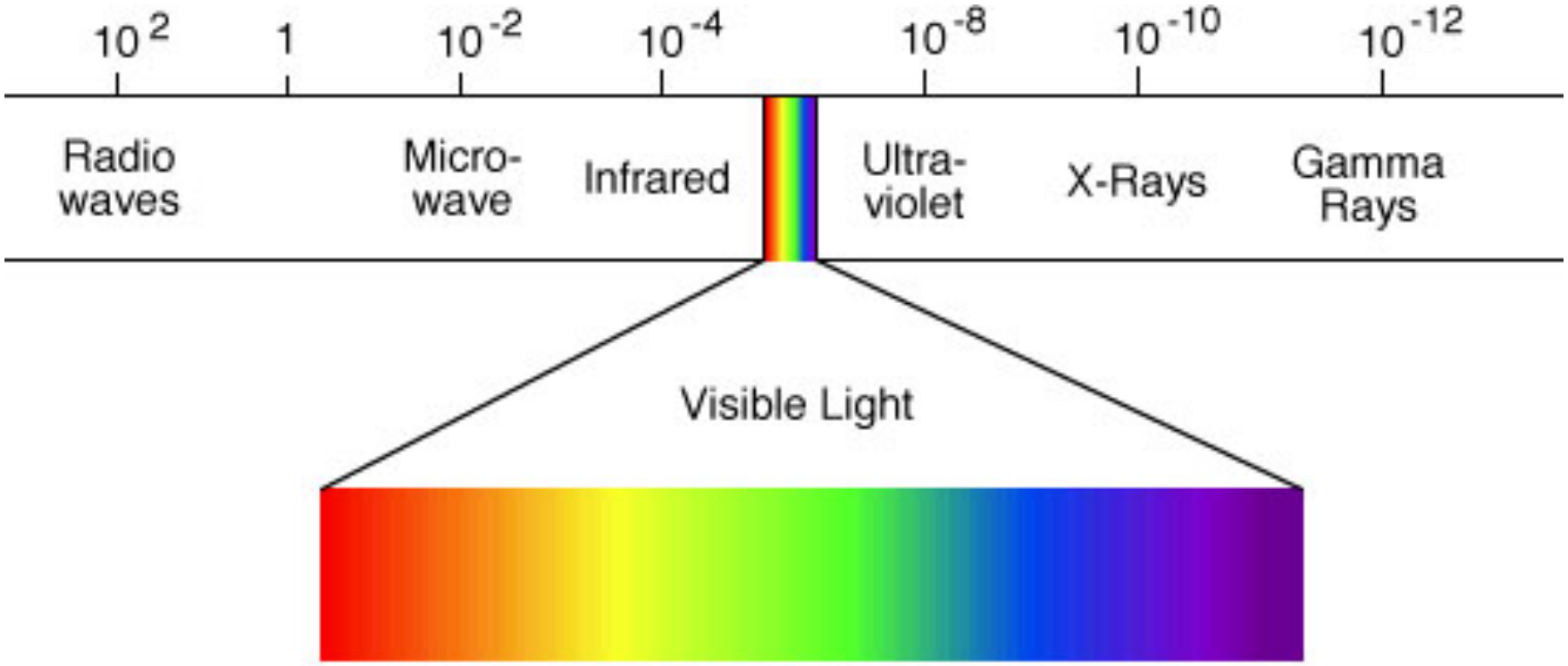


LONG Wavelength

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

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

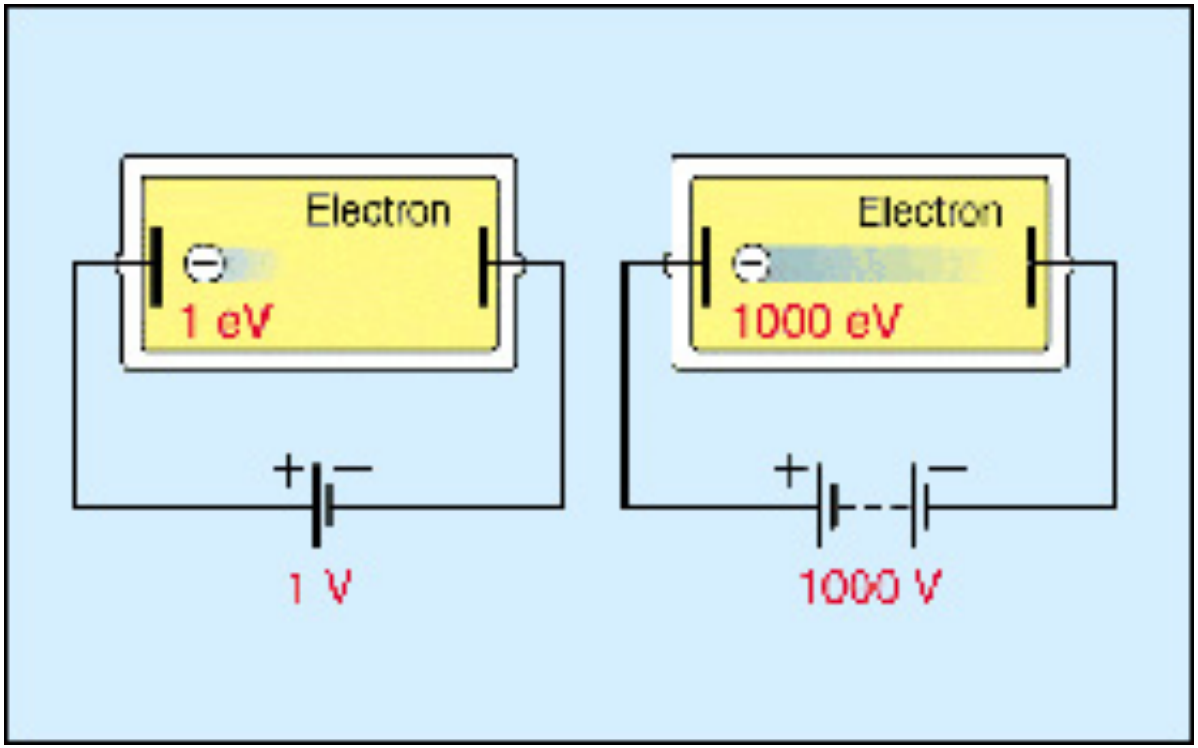
$$E = hf \quad \text{or} \quad E = \frac{hc}{\lambda}$$

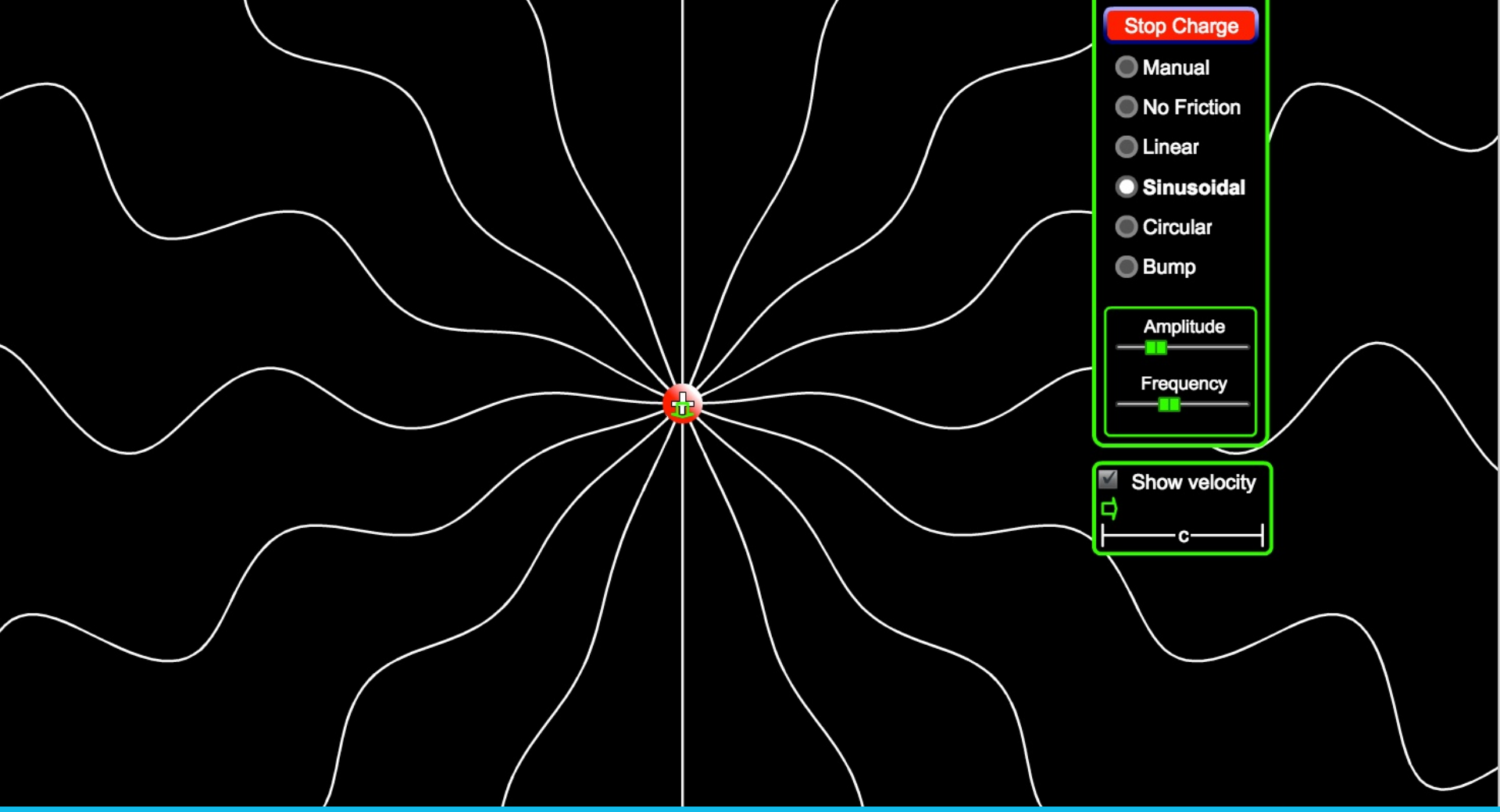
The constant ***h*** is known as the Planck constant, and it is equal to:

$$h = 4.14 \times 10^{-15}\ eV\text{-}s$$

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

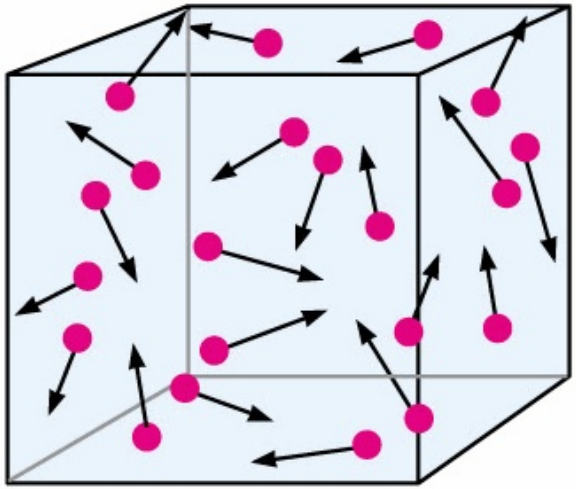
http://phet.colorado.edu/en/simulation/radiating-charge

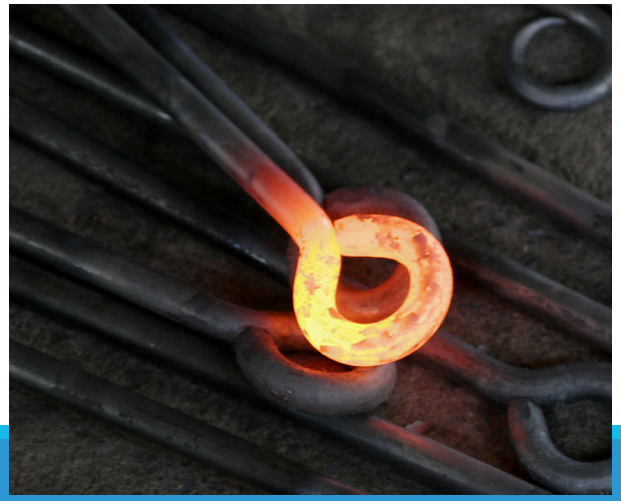
Thermal Radiation

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.





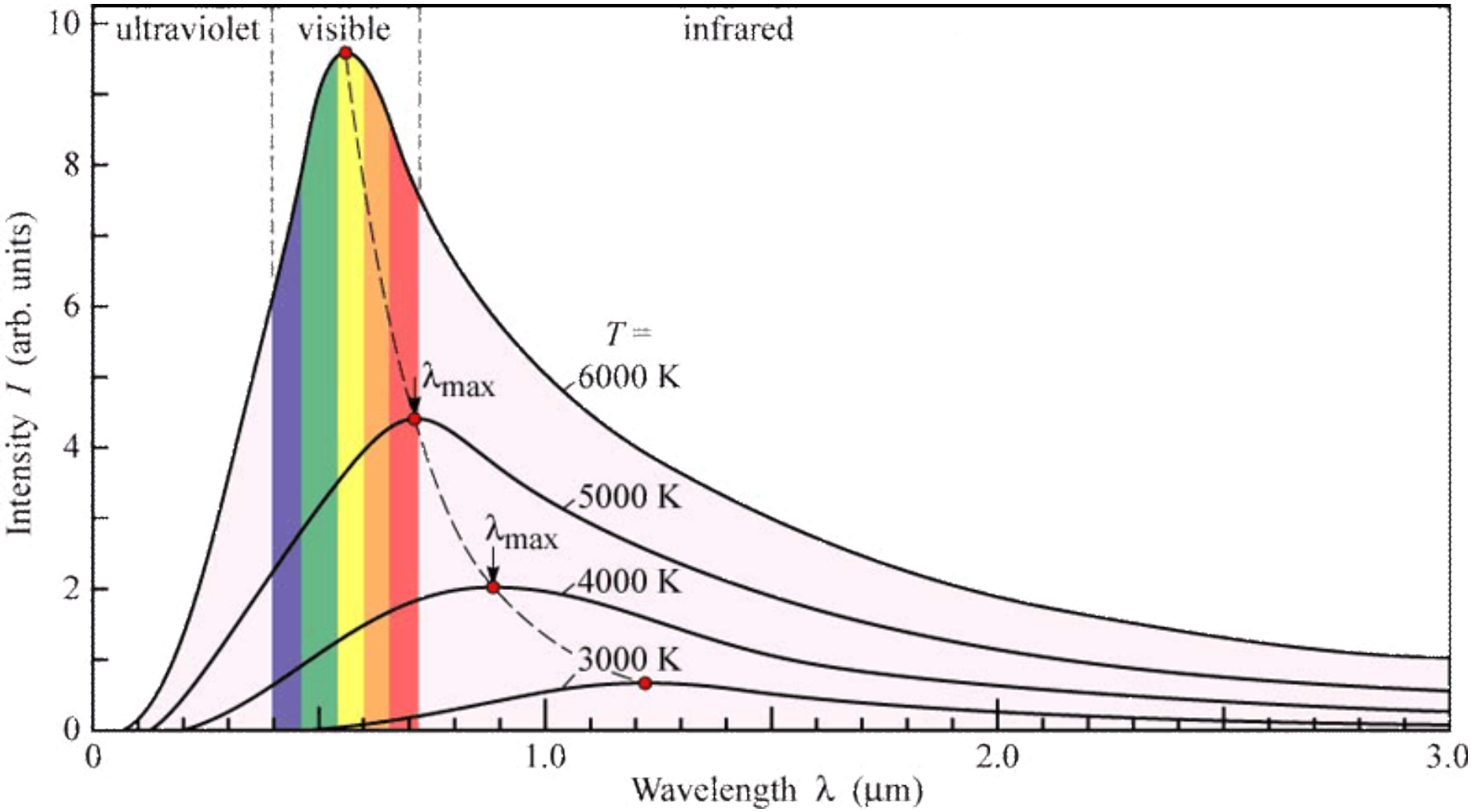
Thermal Radiation Curve

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.


ultraviolet
visible
infrared
10
8
6
4
2
0
Intensity I (arb. units)
T =
6000 K
5000 K
4000 K
3000 K
λmax
λmax
0
1.0
2.0
3.0
Wavelength λ (μm)

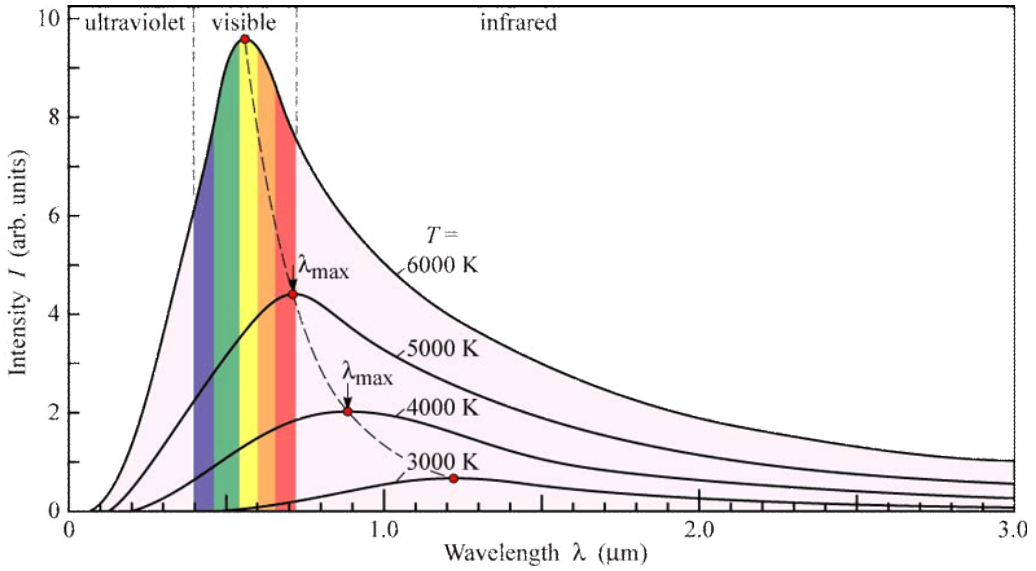
Wavelength of Maximum Intensity

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

$$\lambda_{max} = \frac{2.898x10^{-3}\mathrm{m} * \mathrm{K}}{T}$$

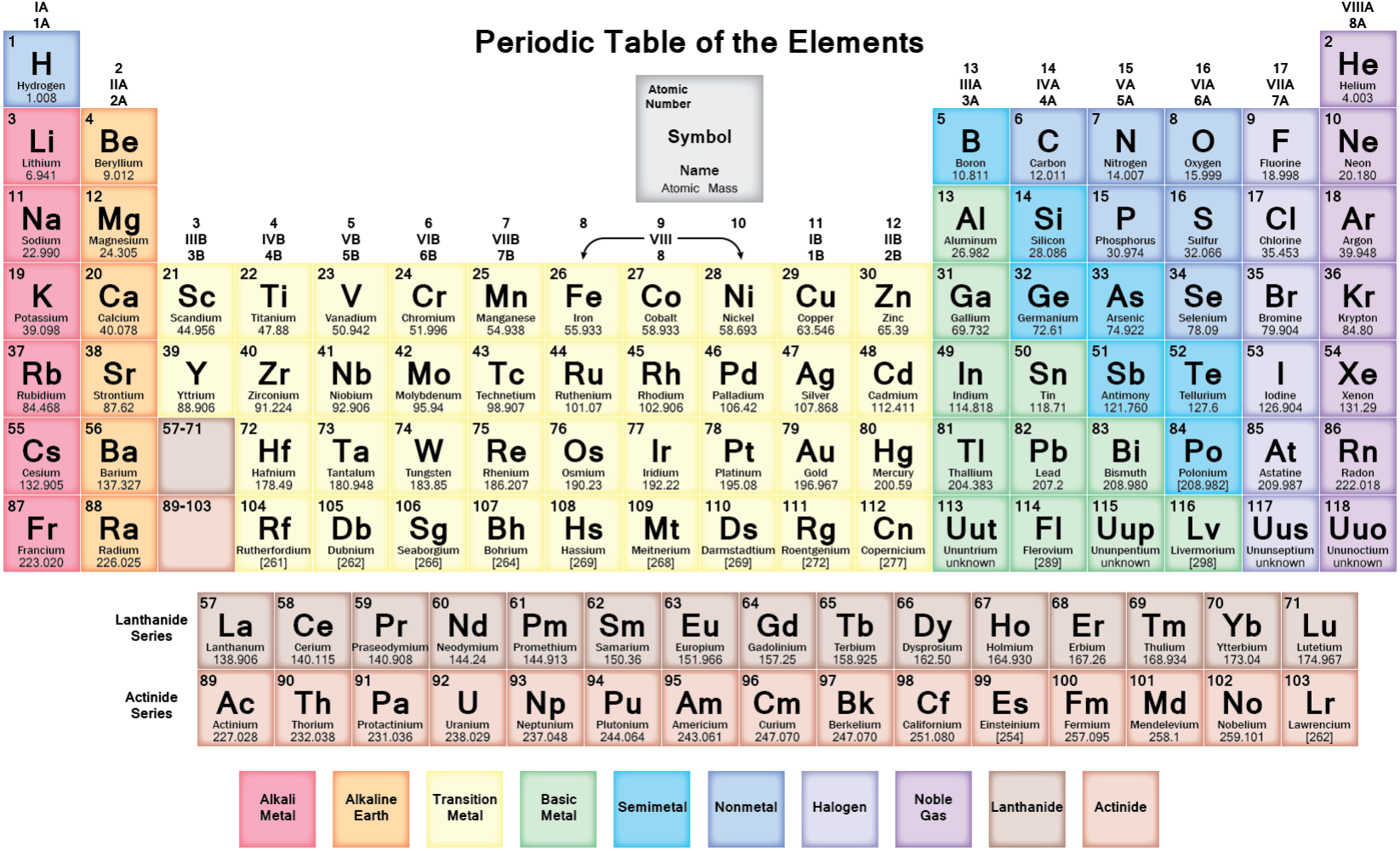
Simulation: Thermal Radiation Curve

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?

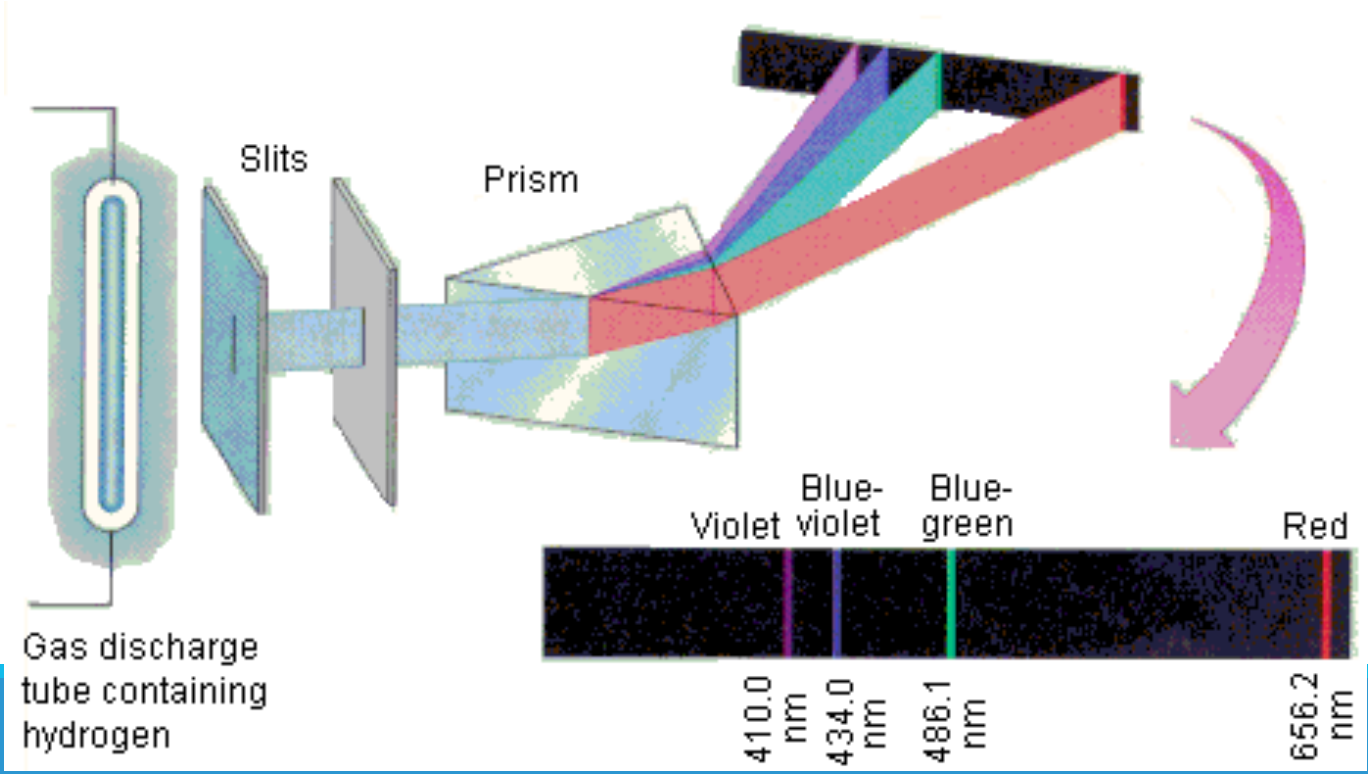


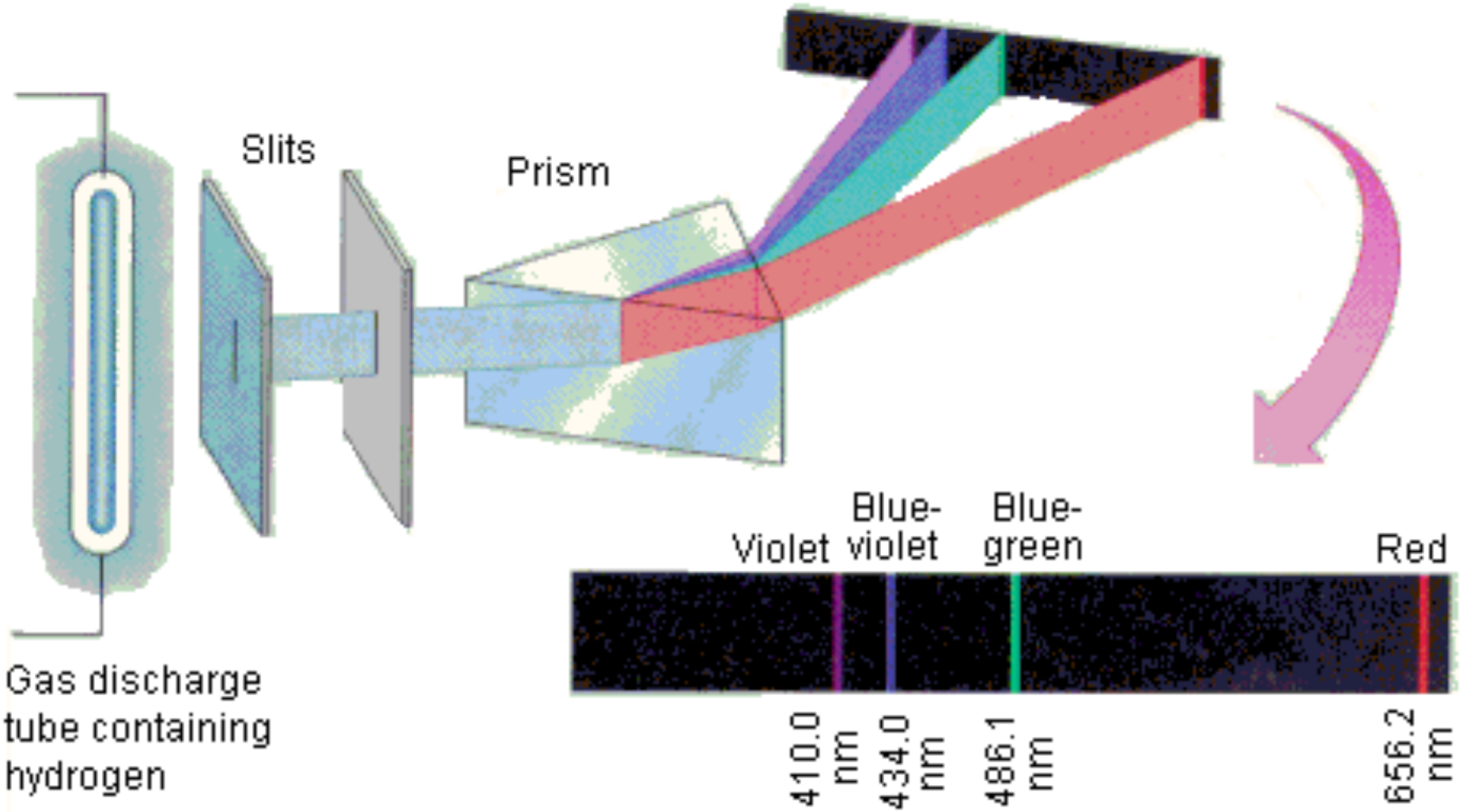
Light from Neon Gas

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.




Slits
Prism
Violet
Blue-violet
Blue-green
Red
Gas discharge tube containing hydrogen
410.0 nm
434.0 nm
486.1 nm
656.2 nm

The Bohr Model of an Atom

The Bohr model of the atom explains this phenomenon.

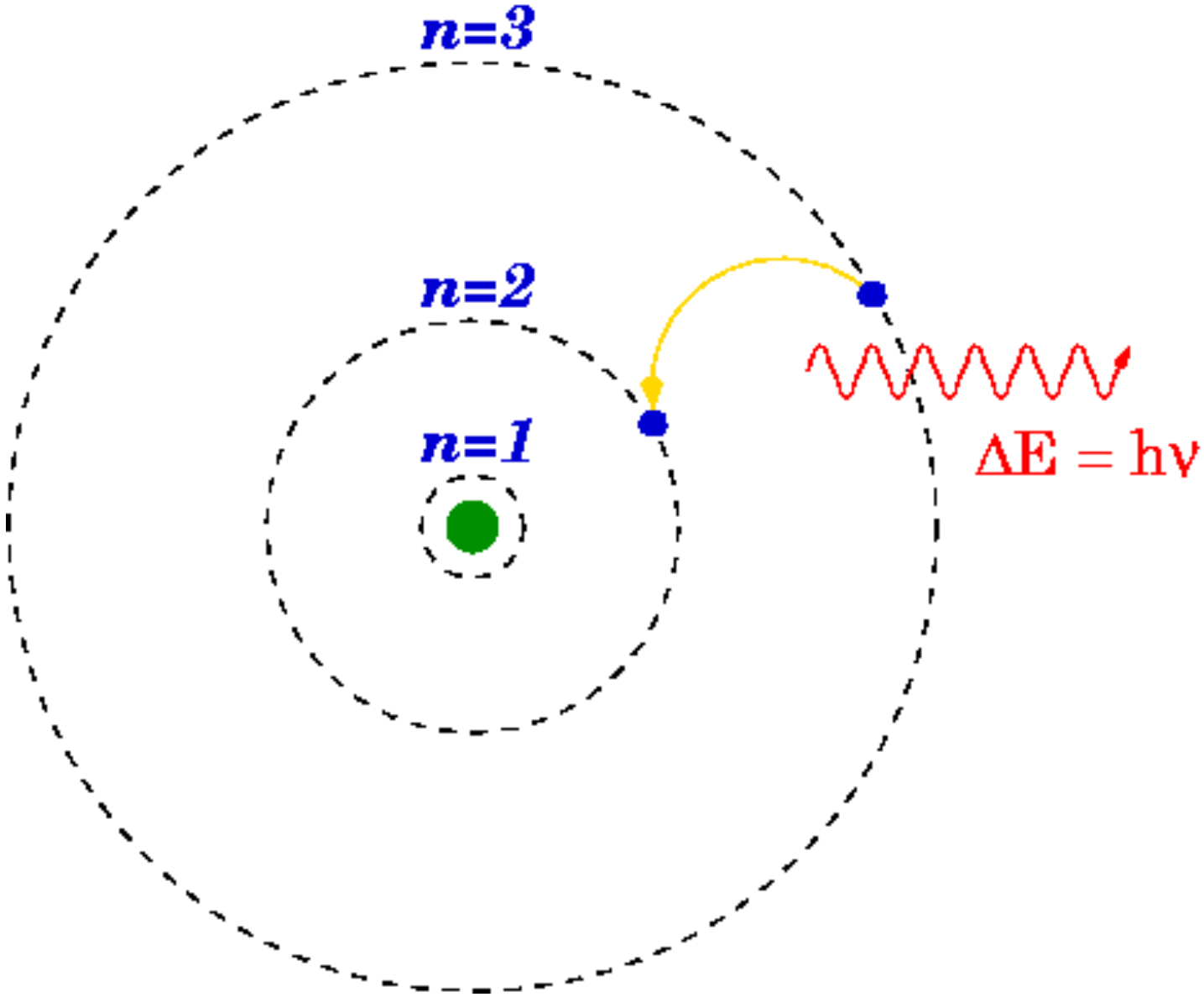
The Bohr model predicts that the electrons in atoms are in orbits of differing energy (called “energy levels”) around the nucleus.

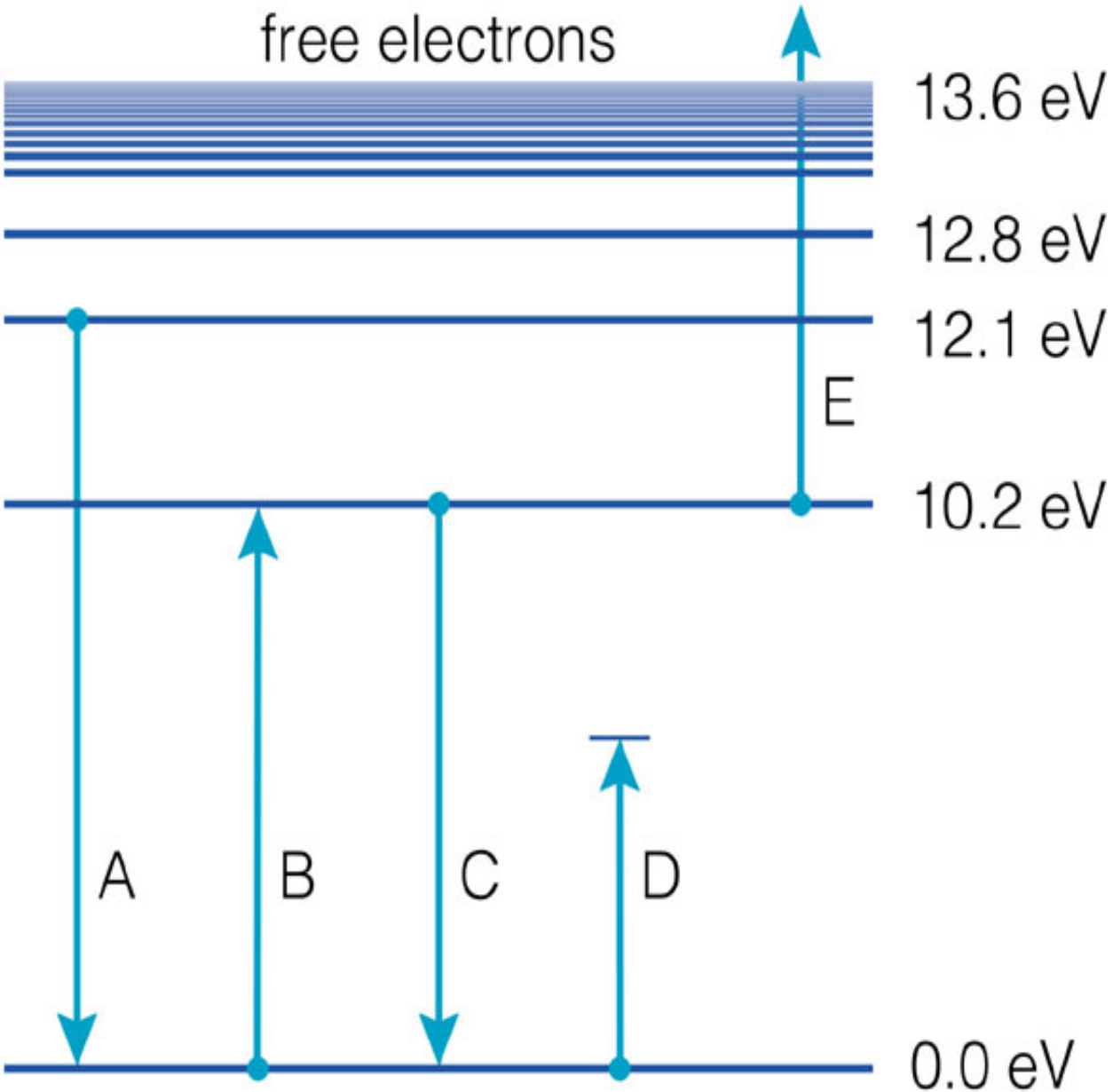
The electron can be in one energy level or another but nothing in between.

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.

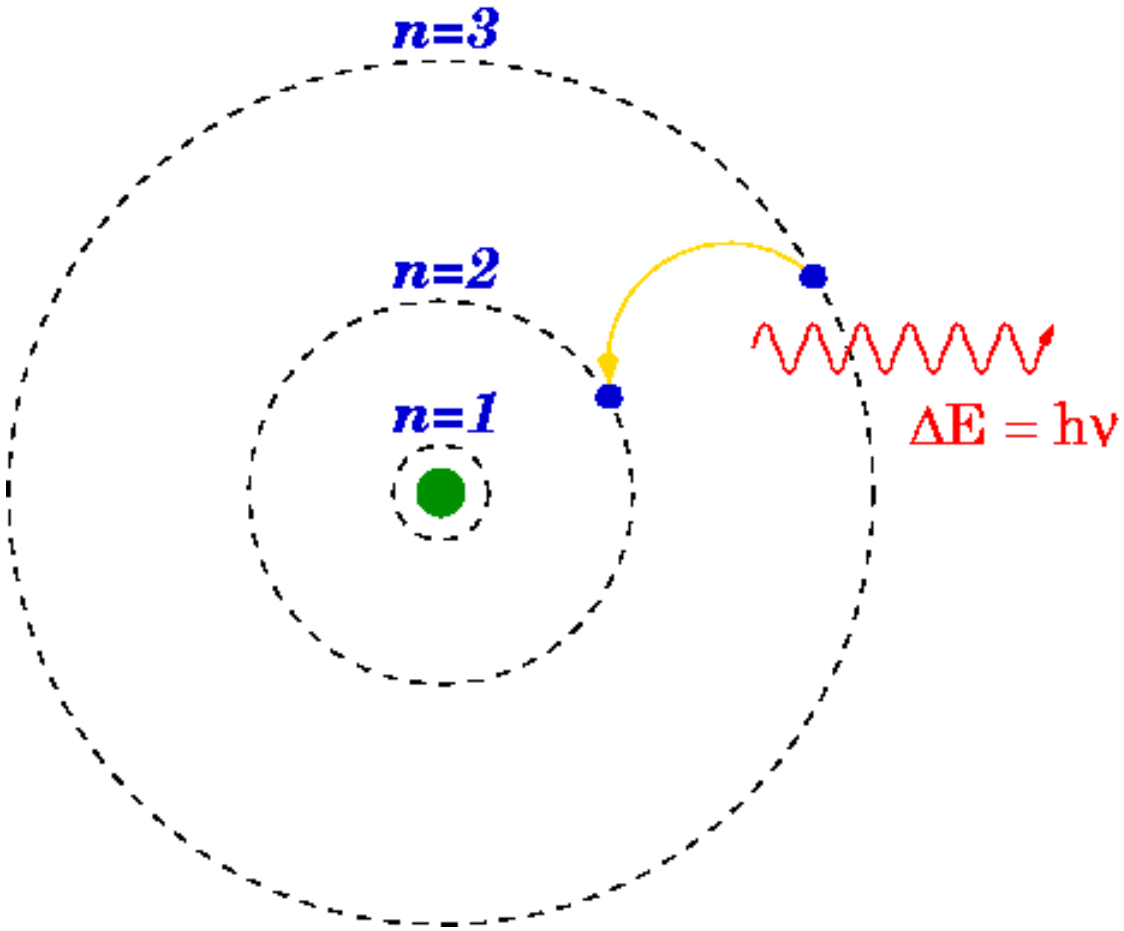

n=3
n=2
n=1
ΔE = hν



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?

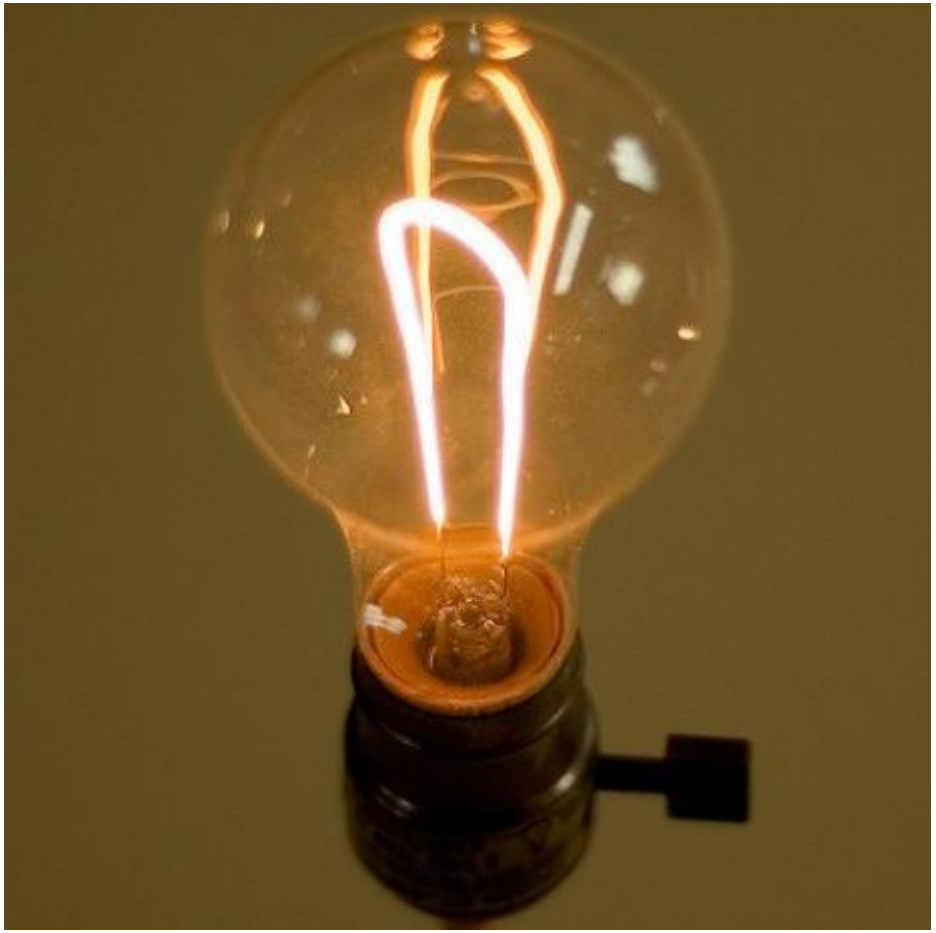
Simulation: Bohr Model of an Atom

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



What causes light?

https://youtu.be/oCEKMEeZXug



Simulation: Neon Discharge Tube

http://phet.colorado.edu/en/simulation/discharge-lamps

Make A Spectrum

Hydrogen

Sodium

Helium

Neon

Mercury

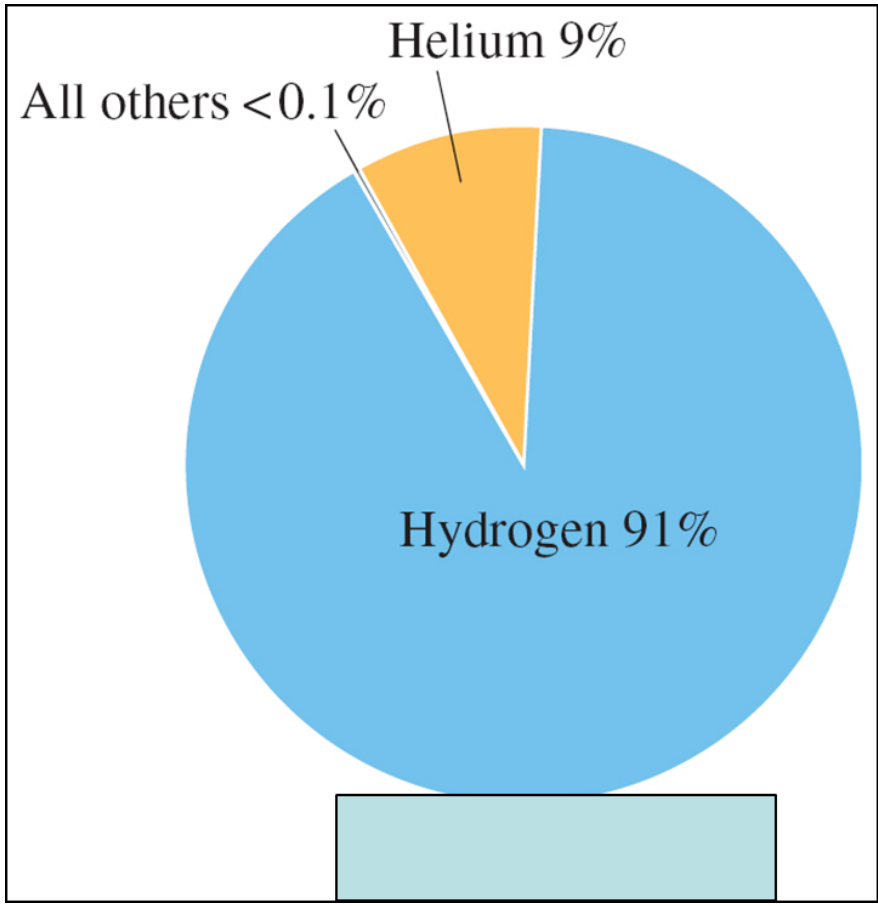
Observations of the Universe

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.

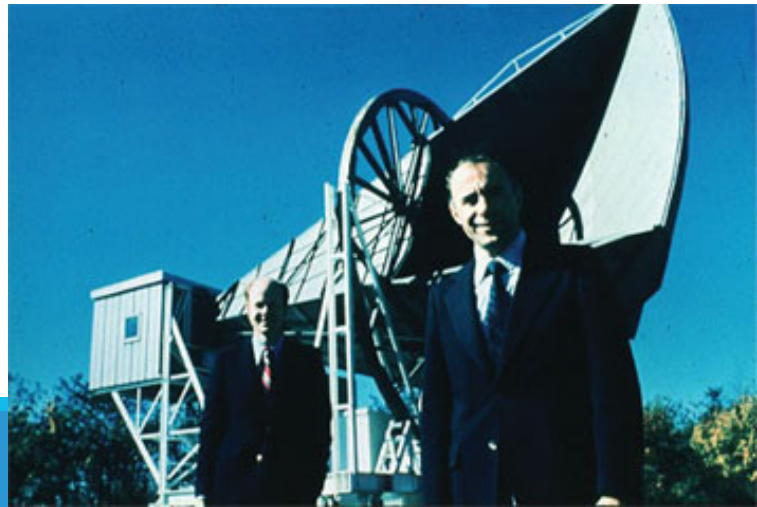


Cosmic Microwave Background

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?***



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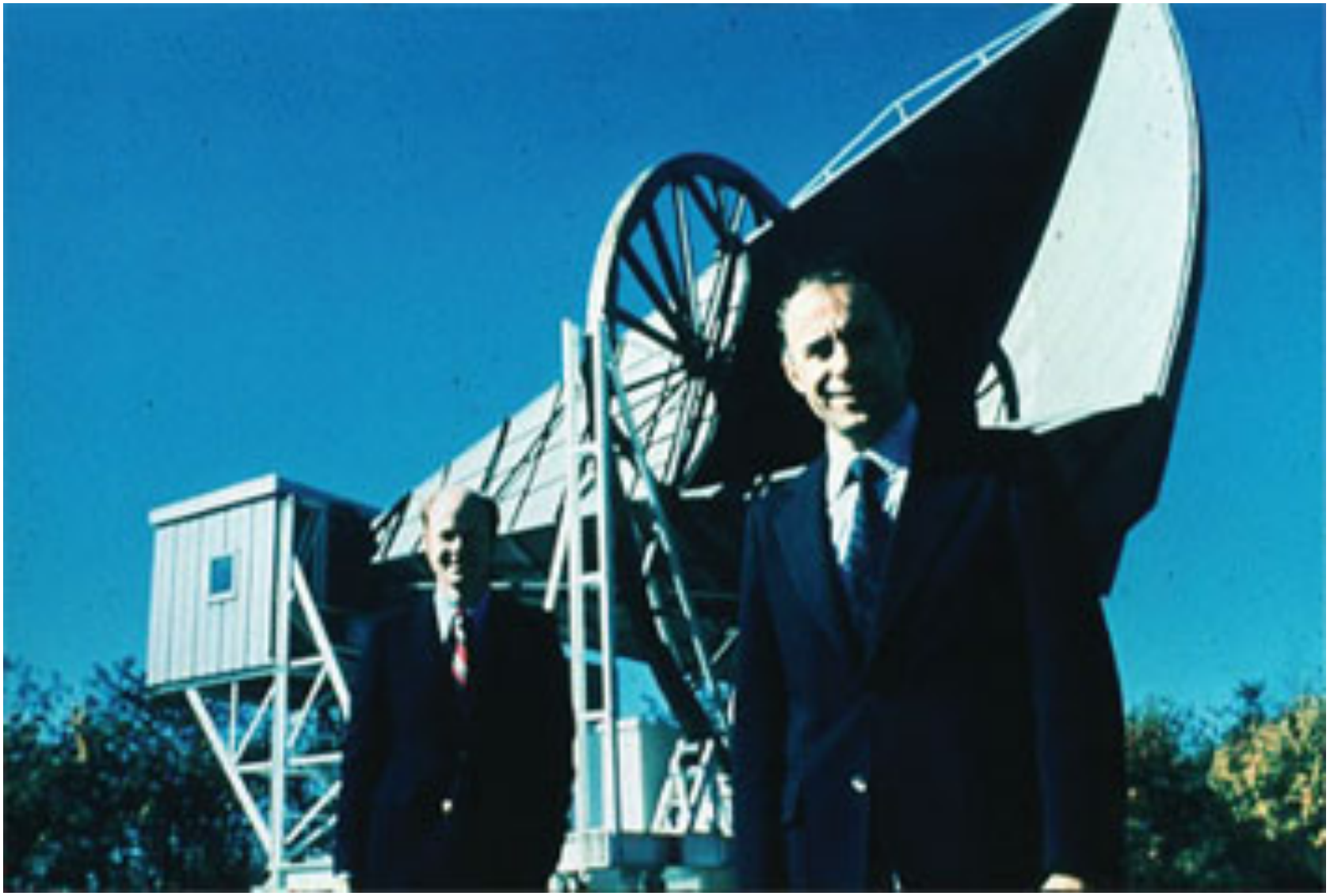
The universe has a temperature of 2.7 K. Any theory of the universe's origins must account for this fact also.



Practice