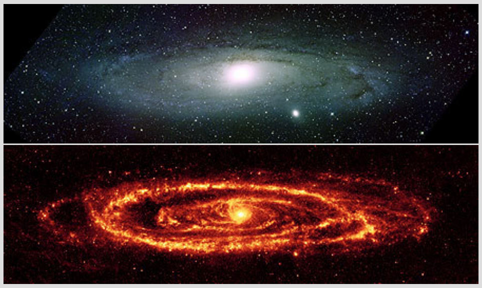
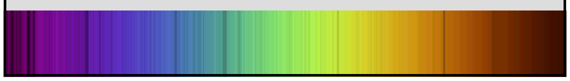
# 6. Light: The Cosmic Messenger





## Agenda

- Announce:
  - “Motion and Gravity” Tutorial due today
  - “Light and Spectroscopy” tutorial due next Thursday
  - Observations Next Week if clear weather
  - Lab on Thursday..Meet in Pell 209 downstairs
- Feedback about what comes after Ch. 7 Telescopes:
  - Spacetime (S2-4)
  - Solar System (8-14)
  - Stars (15-18)
- Discuss Project Ideas
- Ch. 6—Light
- Aspects of Observing

## Astronomical Measurements

- To observe things outside of Earth, what are our options?
  - Smell things?
  - Touch things?
  - Hear things?
  - Taste things?
  - Look at things?
- Which are possible? Impossible?

## 6.1 Light in Everyday Life

Our goals for learning:

- What is the difference between energy and power?
- What are the four ways in which light and matter can interact?

## Power

- **power**: the rate at which energy is used/emitted
- It is measured in units called **watts**.

  1 watt = 1 joule per second
- A 100 watt light bulb radiates 100 joules of energy every second.

## Four Ways in Which Light can Interact with Matter

1. **emission** – matter releases energy as light
2. **absorption** – matter takes energy from light
3. **transmission** – matter allows light to pass through it
4. **reflection** – matter repels light in another direction

## 6.2 Properties of Light

Our goals for learning:

- In what way is light a wave?
- In what way is light made of particles?
- How are wavelength, frequency, and energy related for photons of light?

## Light

A vibration in an electromagnetic field through which energy is transported.

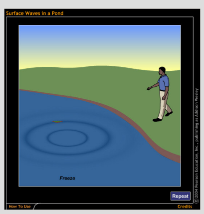
**Dual Natures**

Light as a wave $f\lambda = c$

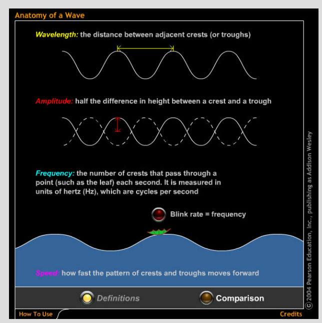
Light as a particle $E = hf$ photon

## Light as a Wave

A *wave* is a pattern which is revealed by its interaction with particles.

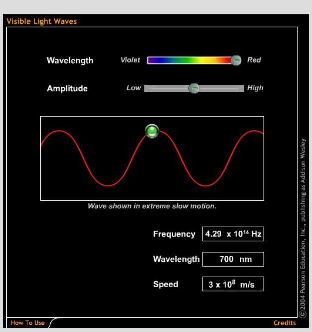



## Properties of a Wave




## Light as a Wave

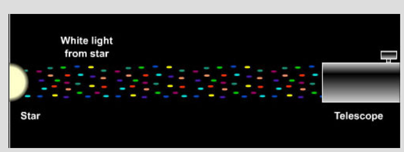
- For a wave, its speed: $s = f\lambda$
- But the speed of light is a constant, c.
- For light: $f\lambda = c$
- The higher $f$ is, the smaller $\lambda$ is, and vice versa.
- Our eyes recognize $f$ (or $\lambda$) as *color*!




## Light as a Particle

- Light can also be treated as *photons* – packets of energy.
- The energy carried by each photon depends on its frequency (color)

  $E = hf = hc / \lambda$ ["h" is called Planck's Constant]
- Bluer light carries more energy per photon.



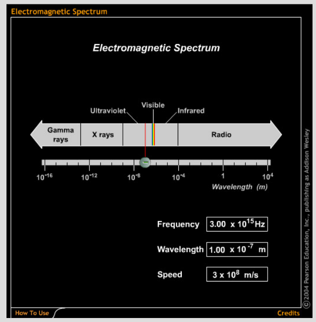
## 6.3 The Many Forms of Light

Our goals for learning:

- List the various forms of light that make up the electromagnetic spectrum.

## The Electromagnetic Spectrum

Most wavelengths of light can not be seen by the human eye.



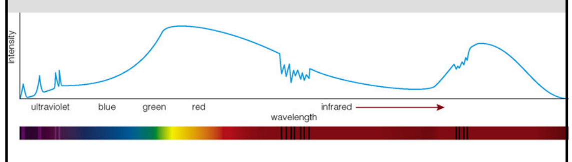

## 6.4 Light and Matter

Our goals for learning:

- How can we use emission or absorption lines to determine the composition of a distant object?
- Are there any material objects that don't give off any light?
- What are the two rules of thermal radiation?

## Light as Information Bearer

We can separate light into its different wavelengths (spectrum).

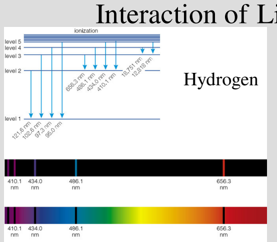





By studying the spectrum of an object, we can learn its:

1. Composition
2. Temperature
3. Velocity

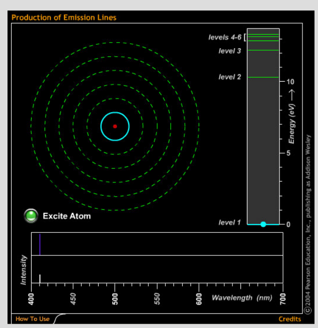
## Interaction of Light with Matter




Hydrogen

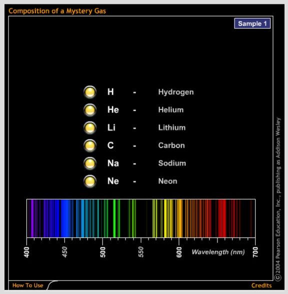
- Remember that each electron is only allowed to have certain energies in an atom.
- Electrons can absorb light and gain energy or emit light when they lose energy.
- It is easiest to think of light as a photon when discussing its interaction with matter.
- Only photons whose energies (colors) match the "jump" in electron energy levels can be emitted or absorbed.

## Emission of Light

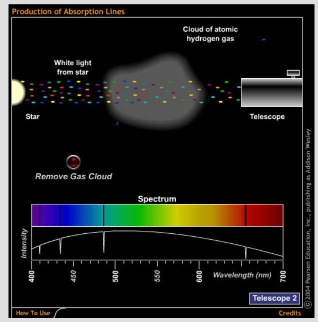


## Emission Spectra

- The atoms of each element have their own distinctive set of electron energy levels.
- Each element emits its own pattern of colors, like fingerprints.
- If it is a hot gas, we see only these colors, called an **emission line spectrum**.

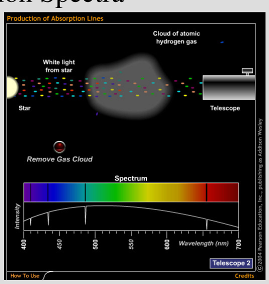



## Absorption of Light




## Absorption Spectra

- If light shines through a gas, each element will absorb those photons whose colors match their electron energy levels.
- The resulting **absorption line spectrum** has all colors minus those that were absorbed.

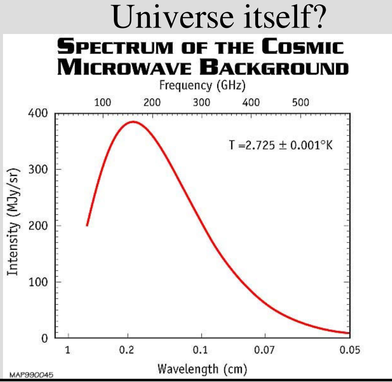



- We can determine which elements are present in an object by identifying emission & absorption lines.

## Thermal Radiation

- Also called *blackbody radiation*
- All objects “glow”..emit such thermal radiation
- Can actually examine radiation to measure an object’s temperature “pyrometer”

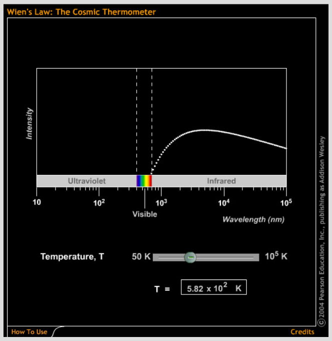
## What’s the temperature of the Universe itself?




## Rules for Emission by Opaque Objects

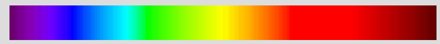
1. Hotter objects emit more total radiation per unit surface area.
   - Stephan-Boltzmann Law
   - $E = \sigma T^4$
2. Hotter objects emit *bluer* photons (with a higher average energy.)
   - Wien Law
   - $\lambda_{max} = 2.9 \times 10^6 / T(K)$ [nm]

# Thermal Radiation




# Kirchhoff's Laws

1 A hot, dense glowing object (solid or gas) emits a continuous spectrum (of *thermal radiation*).



# Kirchhoff's Laws

2 A hot, low density gas emits light of only certain wavelengths --

⇨ an *emission line spectrum*.

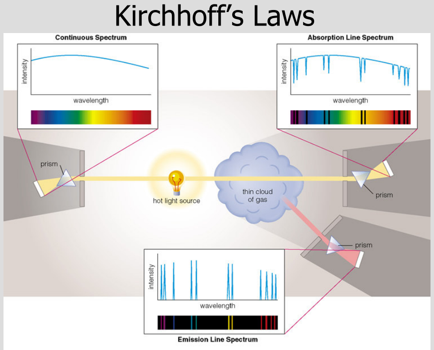



# Kirchhoff's Laws

3 When light having a continuous spectrum passes through a cool gas, dark lines appear in the continuous spectrum --

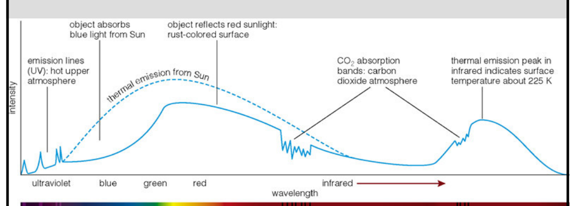
⇨ an *absorption line spectrum*.

# Kirchhoff's Laws






# An Example Spectrum



## 6.5 The Doppler Shift

Our goals for learning:

- What is a Doppler shift?
- What do we learn from a redshift or blueshift?
- How does a star's rotation affect its spectral lines?

## The Doppler Effect

1. Light emitted from an object moving towards you will have its wavelength shortened.

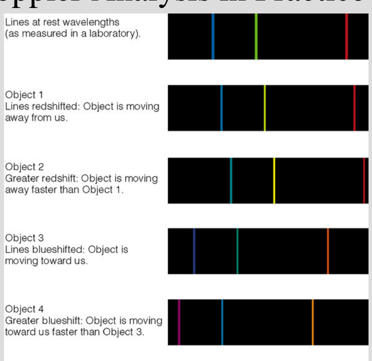
   **BLUESHIFT**

2. Light emitted from an object moving away from you will have its wavelength lengthened.

   **REDSHIFT**

3. Light emitted from an object moving perpendicular to your line-of-sight will not change its wavelength.

## Doppler Analysis in Practice

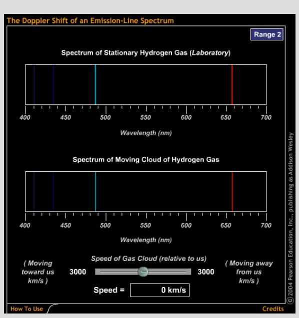



## The Doppler Effect

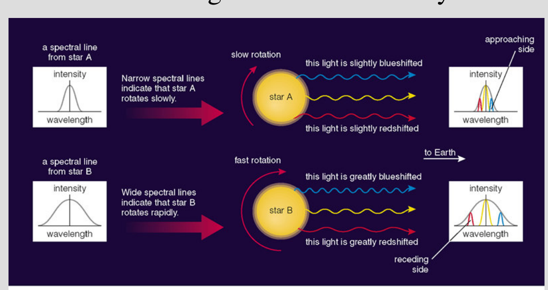
- For small speeds (small compared to?), simple formula: $$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$
- Can compute velocity from wavelength shift

## Measuring Radial Velocity

- We can measure the Doppler shift of emission or absorption lines in the spectrum of an astronomical object.
- We can then calculate the velocity of the object in the direction either towards or away from Earth. (**radial velocity**)




## Measuring Rotational Velocity



## What have we learned?

- What is the difference between energy and power?
  - Power is the rate at which energy is used. The standard unit of power is 1 watt = 1 joule/s.
- What are the four ways in which light and matter can interact?
  - Matter can emit, absorb, transmit, or reflect light.
- In what way is light a wave?
  - Light is an electromagnetic wave – a wave of vibrating electric & magnetic fields – characterized by a wavelength and a frequency and traveling at the speed of light.

## What have we learned?

- In what way is light made of particles?
  - Light comes in individual photons, each with a specific energy that depends on its frequency.
- How are wavelength, frequency, and energy related for photons of light?
  - Frequency increases when wavelength decreases, and vice versa. Energy is proportional to frequency.
- List the various forms of light that make up the electromagnetic spectrum.
  - In order of increasing frequency (energy), the forms of light are: radio, infrared, visible light, ultraviolet, X-rays, and gamma-rays.

## What have we learned?

- How can we use emission or absorption lines to determine the composition of a distant object?
  - Emission or absorption lines occur only at specific wavelengths corresponding to particular energy level transitions in atoms or molecules. Each chemical element has a unique spectral signature consisting of a particular set of emission or absorption lines.
- Are there any material objects that don't give off any light?
  - No. All objects radiate light by virtue of their temperatures. This light is called thermal radiation.

## What have we learned?

- What are the two rules of thermal radiation?
  - (1) Hotter objects emit more total radiation per unit area. (2) Hotter objects emit photons with a higher average energy.
- What is a Doppler shift?
  - It is a shift in the wavelength of an object's light caused by its motion toward or away from us.

## What have we learned?

- What do we learn from a redshift or blueshift?
  - It tells us how fast the object is moving away from us (redshift) or toward us (blueshift). The Doppler shift does not tell us about motion across our line of sight.
- How does a star's rotation affect its spectral lines?
  - Because of Doppler shifts, faster rotating stars have broader spectral lines.

***We should not expect to see an optical emission line spectrum from a very cold cloud of hydrogen gas because***

1. hydrogen gas does not have any optical emission lines.
2. the gas is too cold for collisions to bump electrons up from the ground state (lowest energy level).
3. hydrogen gas is transparent to optical light.
4. emission lines are only found in hot objects.
5. cold objects only produce absorption lines.

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***If you could view a spectrum of light reflecting off a blue sweatshirt, you'd see an entire rainbow of colors.***

1. Yes, a reflected spectrum is exactly the same as a transmitted spectrum.
2. Yes, but the reflected spectrum would be enhanced in blue light compared to other colors.
3. No, only blue colors would be reflected and other colors would pass through the sweatshirt.
4. No, only blue colors would be reflected and other colors would be absorbed by the sweatshirt.
5. No, all the colors would reflect back as blue.

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***If the Sun's surface became much hotter (while the Sun's size remained the same), the Sun would emit more ultraviolet light but less visible light than it currently emits.***

1. Yes, because the visible light would be absorbed by the Sun's warmer surface.
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3. No, the Sun's warmer surface would emit less light at all wavelengths.
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5. No, because if the Sun's size remained the same, the amount of light emitted would remain the same at all wavelengths.

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***If you had X-ray vision, then you could read an entire book without turning any pages.***

1. Yes, but you would not be able to differentiate between different optical colors.
2. Yes, but all the pages would merge into one.
3. No, a book doesn't emit X-rays so you wouldn't see anything.
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***If a distant galaxy has a substantial redshift (as viewed from our galaxy), then anyone living in that galaxy would see a substantial redshift in a spectrum of the Milky Way Galaxy.***

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3. Yes, but we would measure a lower redshift than they would.
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***When you pay your power bill to LIPA (?), you're paying for each***

1. Unit of power, watts, used.
2. Unit of energy, joules, used.
3. Unit of force, newtons, used.
4. Unit of acceleration, m/s^2, used.
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***I'm building a device that sends out waves of light as specified by a user. It's going to be as controllable as possible, and therefore I need to place dials on the box for***

1. Wavelength, frequency, speed, and amplitude.
2. Frequency, speed, and amplitude.
3. Wavelength, frequency, and speed.
4. Wavelength and frequency.
5. Wavelength and amplitude.

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5. **Wavelength and amplitude.**

# Aspects of Observing

## What's out there to see?

- Open clusters—young group of stars clumped together, view resembles that of twinkling jewels
- Galaxies—view resembles a little cloud of light
- Globular clusters—group of hundreds of thousands of stars within our own galaxy
- Diffuse nebulae—clouds of gas and dust from which young stars form (e.g. Orion Nebula)
- Planetary nebulae—hollow shells of gas thrown out by old stars (e.g. Ring, Dumbbell)
- Planets—often bright and easy

## The Planets

- Bright and small—use high power eyepiece
- Follow the ecliptic
- Rise high in the winter (opposite Sun's daytime path)
- Don't twinkle
  - Uranus/Neptune—faint and small, greenish disks
  - Mars—bright red, polar ice caps may be visible

## Tips

- Ideal sky conditions:
  - Low humidity, cloudless
  - Stable air (no large temperature gradients
  - Little light pollution
- Setup telescope(s) 15 minutes before observing to equalize temperature—avoid convection currents in air inside
- Get your eyes dark adapted—don't look at bright lights, use red covered flashlights

## Winter Guideposts

- Big Dipper's forward bowl edge points up to Polaris
- 5 bright stars in "W" shape are Cassiopeia
- Aldebaran—brightest star in Taurus

## Stuff We may see

- Mars
- Andromeda (M31)—a galaxy
- The Pleiades (M45)—an open cluster
- Open Clusters of Cassiopeia
- Uranus and Neptune
- Which constellations?