Light and Telescopes

Physical Sciences
Broward College
Prepared for AST 1002
Horizons in Astronomy

James P. Joule

- 1818 - 1889
- Born to a brewery family in Salford, Lanchsire, England
- Studied at home and published many papers on heat transfer
- Became the head of the Joule Brewery
- Combined the effort many scientists to create Kinetic Molecular Theory (KMT)
- KMT led to the discovery of atoms and how light was produced.

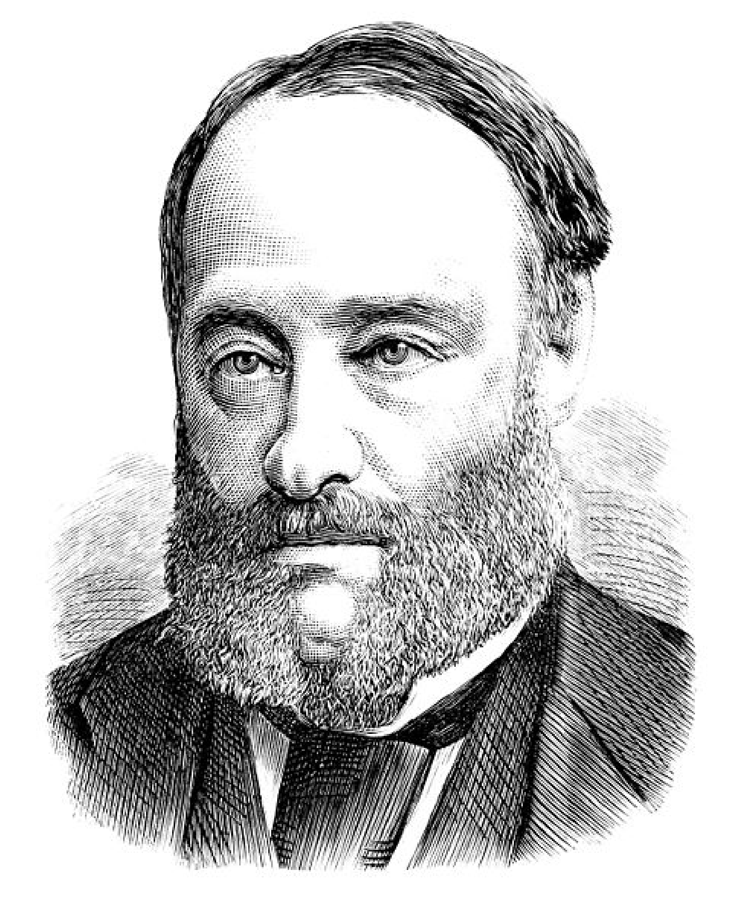


Figure 1. James P. Joule (Wiki)

Energy and Power

Energy (Also Known As Work)

- A force through the distance.
- W = F*d
- Units of Work
  - 1 unit of work = 1 N * 1m
  - 1 kg m^2/s^2 = 1 Joule

Power

- Energy produced over a period of time
- P = E/t
- Units of Power
  - 1 unit of power = 1 Work / time
  - 1 Joule/ Second = 1 Watt

Kinetic Energy

$$W = Fd$$
$$F = ma$$
$$d = \frac{1}{2}at^2$$
$$a = \frac{v}{t}$$
$$a^2 = \frac{v^2}{t^2}$$

$$W = ma\left(\frac{1}{2}at^2\right)$$
$$W = \frac{1}{2}ma^2t^2$$
$$W = \frac{1}{2}m\left(\frac{v^2}{t^2}\right)t^2$$
$$W = \frac{1}{2}mv^2$$

Potential Energy

$$W = Fd$$
$$d = h$$
$$F = ma$$
$$a = g$$
$$W = mgh$$

Kinetic Energy of Car

- The car from the Galileo and Newton lesson is moving at 30 m/s. What is the kinetic energy of the car?

$$m = 2{,}000kg$$

$$v = 30\, m / s$$

$$W = \frac{1}{2} m v^2$$

$$W = \frac{1}{2}(2{,}000kg)(30\, m / s)^2 = 90{,}000 kgm^2 / s^2 = 90{,}000\, J$$

Potential Energy of a Car

- What is the potential energy of the above car when it is on a hill of 300 m?

$$m = 2{,}000kg$$

$$h = 300\,m$$

$$W = mgh$$

$$W = (2{,}000kg)(9.8m/s^2)(300m) = 5{,}880{,}000kgm^2/s^2 = 5{,}880{,}000\,J$$

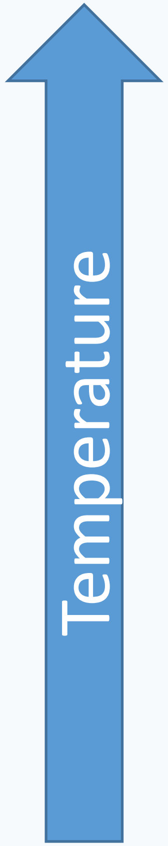
Conservation of Energy

- “Energy is never created or destroyed. Energy can be converted to one form to another but the total energy remains the same.”
- Work against:
  - Inertia: conserved
  - Gravity: conserved
  - Friction: not conserved, heat released
  - Shape: not conserved, heat transferred

Kinetic Molecular Theory

- Democritus (5th Century B.C.)
  - Introduced atoms
  - Rejected by Aristotle
    - Elements represented by earth, air, fire, and water
  - Galileo and Newton suggested he might be right, but not confirmed
  - Introduced Kinetic Molecular Theory
- Molecules
  - Made of atoms
  - Compounds like H_20
  - Smallest compound components
    - Diatomic – O^2
    - Monatomic – H
  - Interactions
    - Cohesion – like atoms
    - Adhesion – unlike atoms

The Results of the Kinetic Molecular Theory



- Phases of matter
  - Gas
    - Variable Volume and shape
    - Can be pressurized
    - Vapor (hyper-hydrated) and Plasma (hot, charged) are special states of gases
  - Liquid
    - Fixed Volume, Variable Shape
    - Can't be pressurized
  - Solid
    - Fixed Volume, Fixed Shape
    - Can be pressurized

- Molecule motion
  - Diffusion
  - Average Kinetic Energy
- Temperature is related to the molecular motion; the higher the temperature, the more molecular motion.
- Observations of light gave us a window on why these molecules move.

Pathways of Light

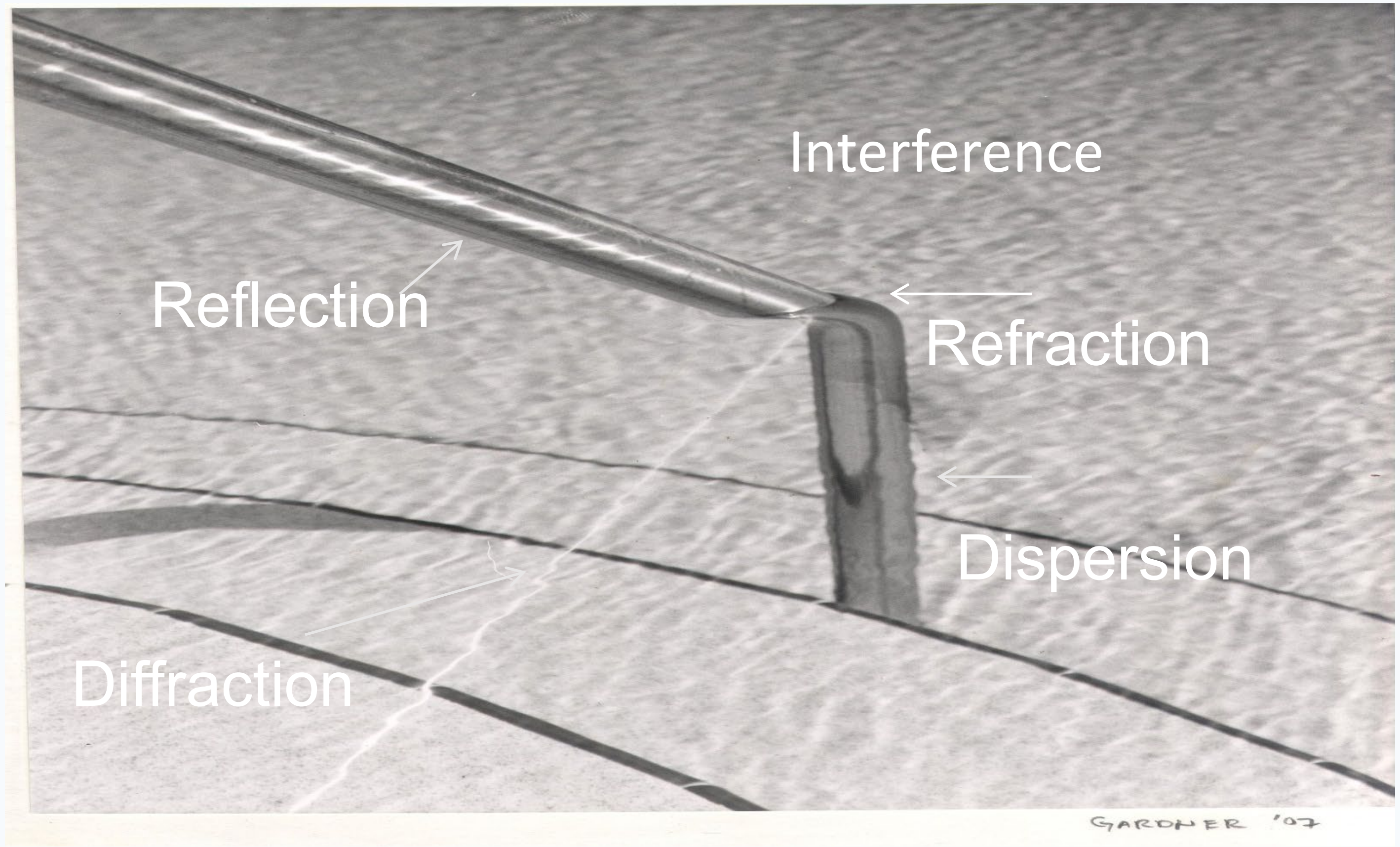


Figure 2. Photography Project, Gardener, 2007

Refraction and Reflection

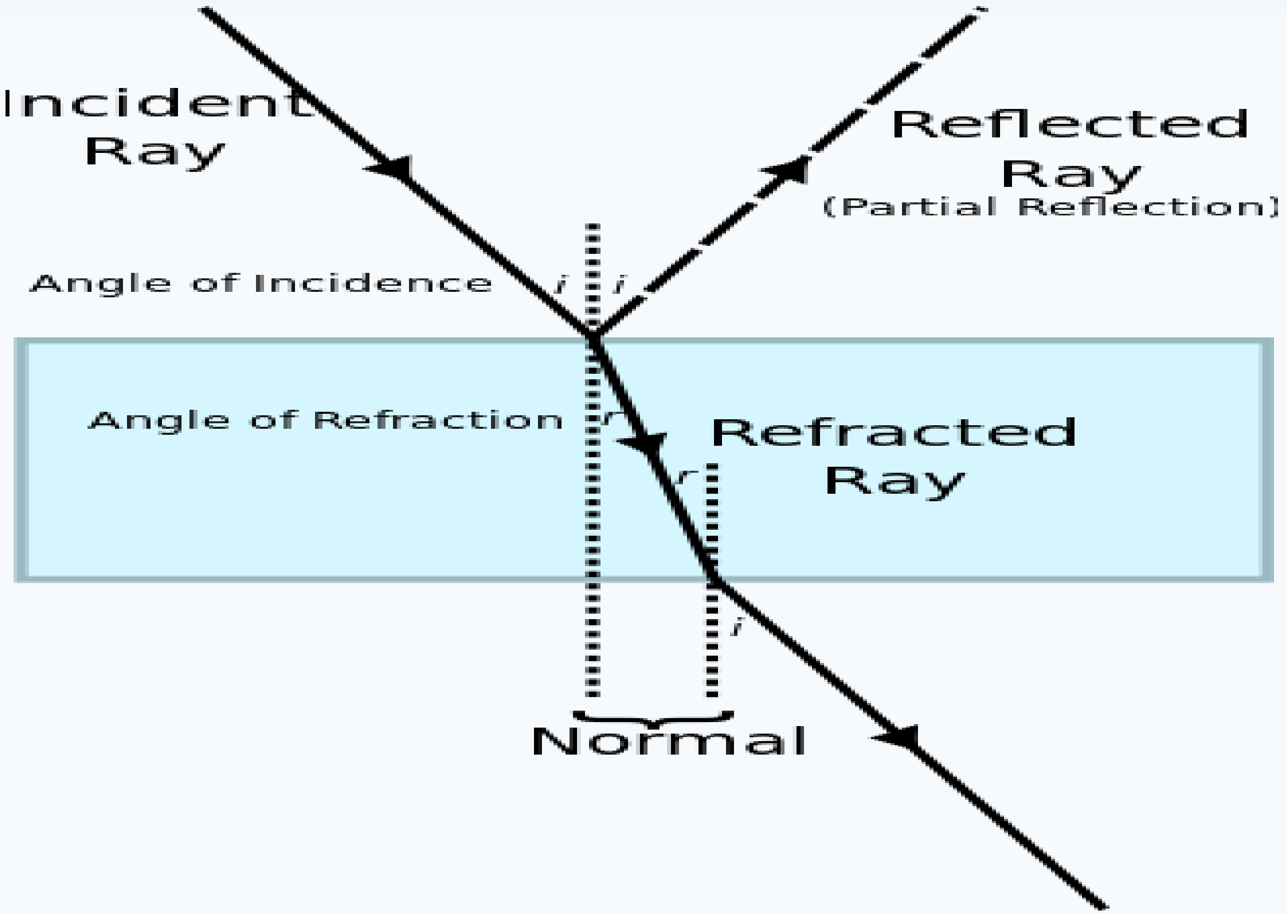


Figure 3. Refraction and Reflection in a medium (Wiki)

Wave Nature of Light – Diffraction

- Christian Huygens first explored the diffraction nature of light.
- Light bending around an opaque object
- Diffraction spikes on the star are produced from light bending around stress points in the mirror in the Hubble Telescope.

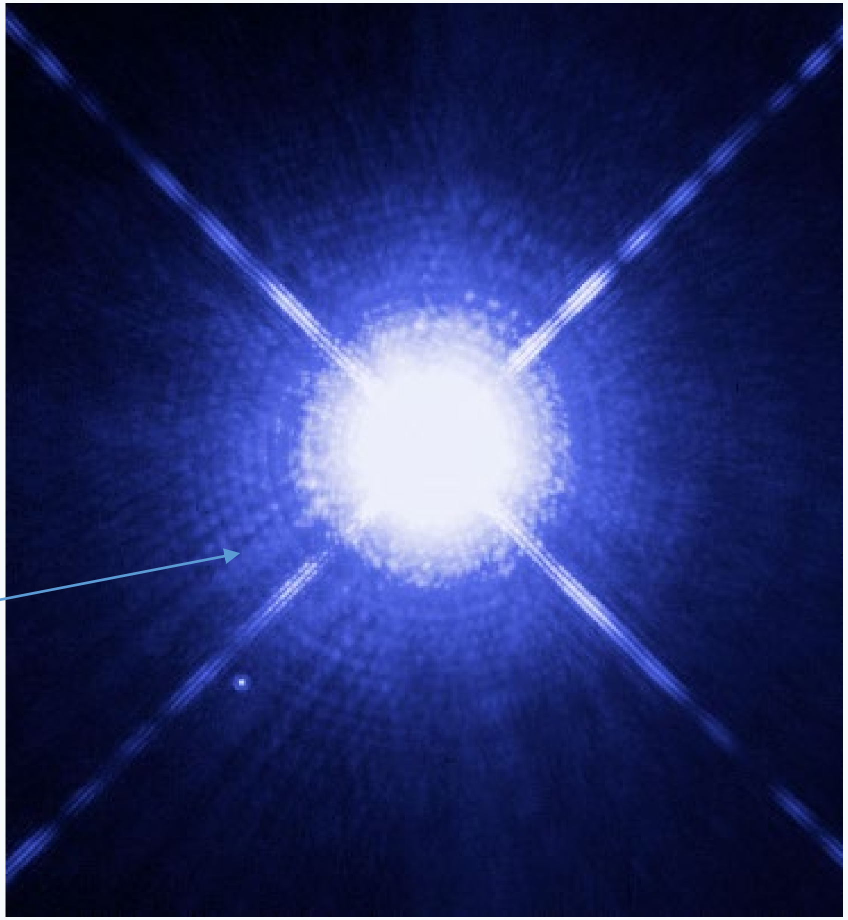
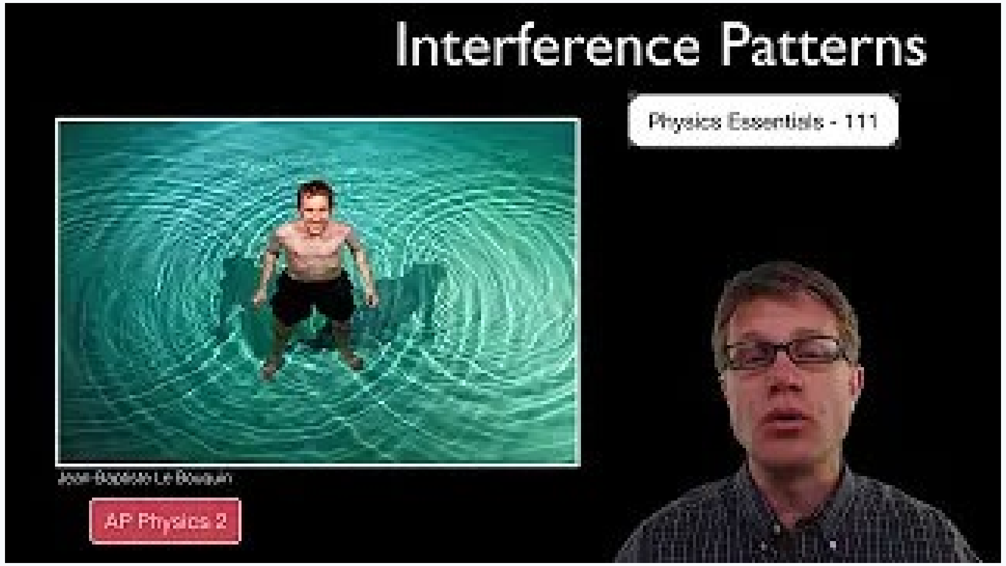


Figure 4. Diffraction (Wiki)

Wave Nature of Light - Interference

- Waves interacting with each other create areas of superposition (addition) and interference (subtraction).
- Click on the image to see how interference works.



Particle Nature of Light - Lensing

- Einstein and Planck exposed metal to different colors of light and found different, specific energies needed to stop the flow of electrons.
- This led to the idea that light was carried by the particle called the photon
- Photons are diverted around gravitational objects like pebbles rolling around rocks in a rock slide.

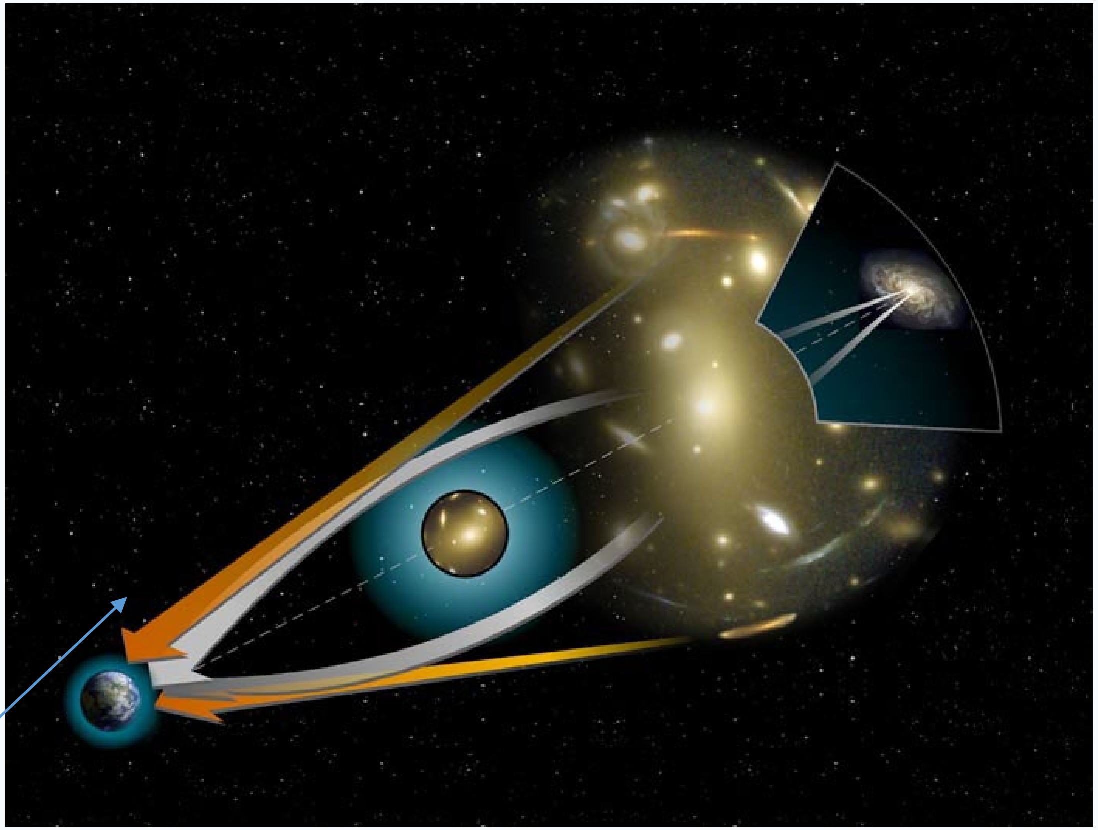


Figure 5. Galactic Lensing (Wiki)

Particle Nature of Light - Dispersion

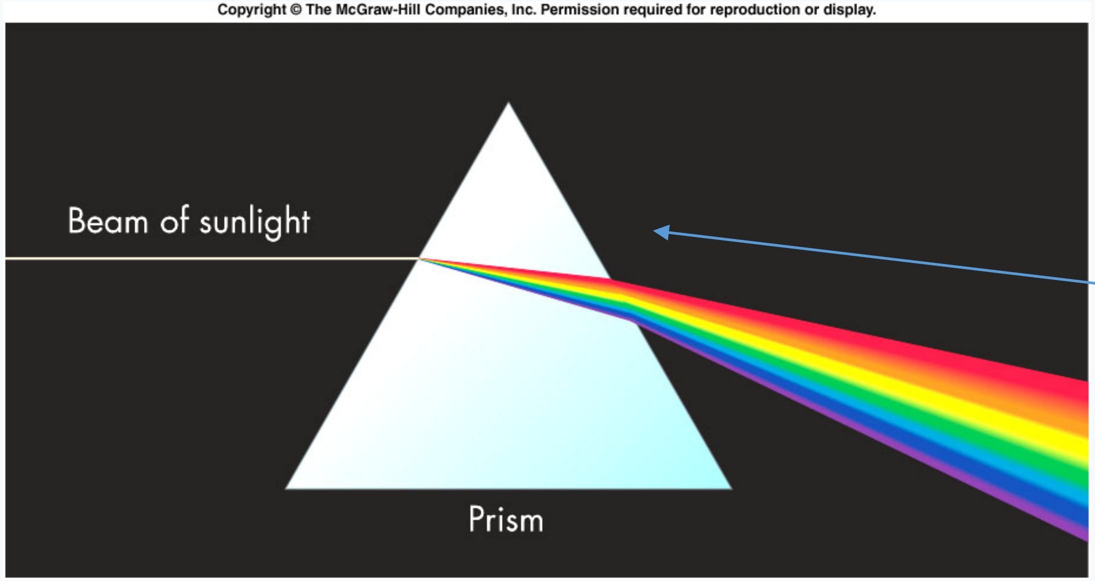


Figure 6. Dispersion of Light by Prism (Fix, 2004)

- The prism works because the different energies of the light. Each is refracted more or less in the glass.
- We see a spectrum from this dispersion.

Photons

Particles – Light behaves like a particle in the macro world.

Waves – Light behaves like a wave in the micro world.

Both are confined by wavelength.

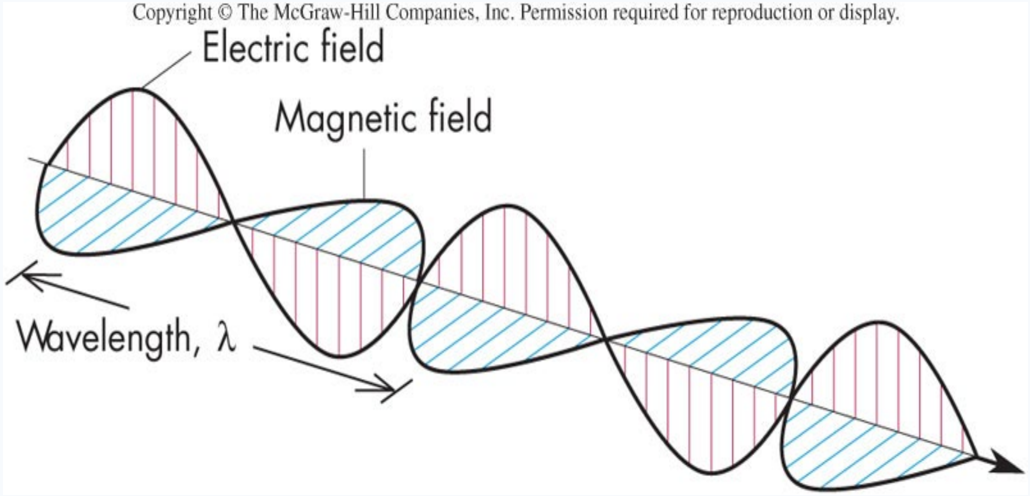


Figure 7. A Photon as a Particle (Fix, 2004)

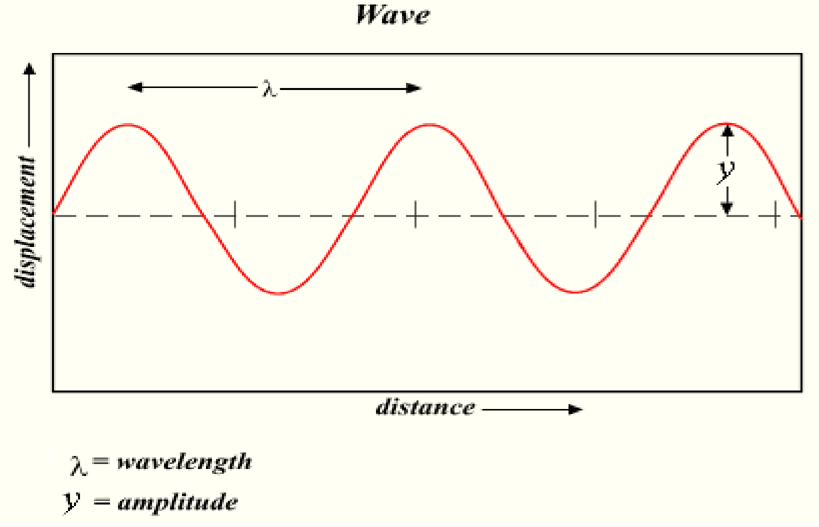


Figure 8. A Wave of Light (Wiki)

Electromagnetic Spectrum

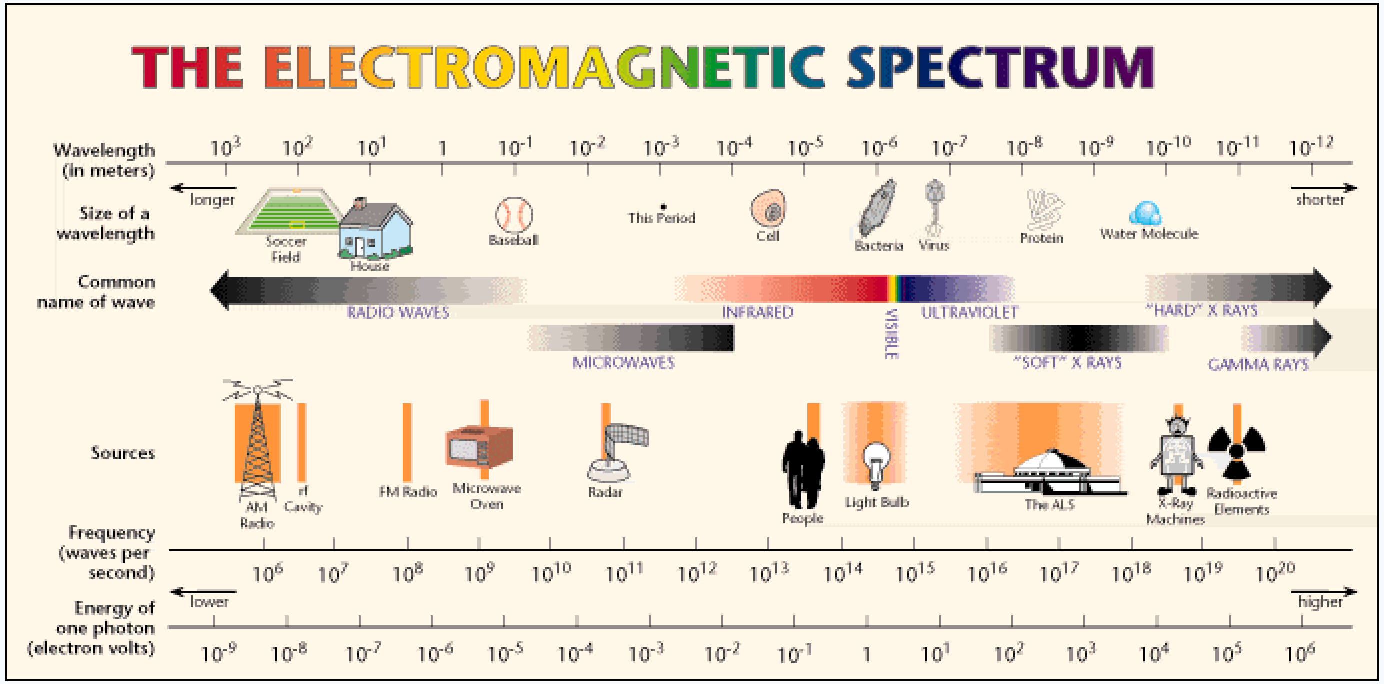


Figure 9. The Electromagnetic Spectrum (Moxon, 2001)

Frequencies and Energy

Frequency

$$frequency = \frac{1}{Period}$$

$$c(speed\ of\ light) = \lambda f$$

$$f = \frac{c}{\lambda}$$

$$c = 2.997X10^{8}\, m/s$$

Energy

$$E = hf$$

$$h = 6.626X10^{-34} Js$$

Wavelength of Light

- If a wavelength of a light wave is $6.563X10^{-7}$ m, what is the frequency of this light?

$$\lambda = 6.563X10^{-7}m$$

$$f = \frac{c}{\lambda} = \frac{2.997X10^{8}m/s}{6.563X10^{-7}} = 4.567X10^{14}Hz$$

Gustav Kirchoff

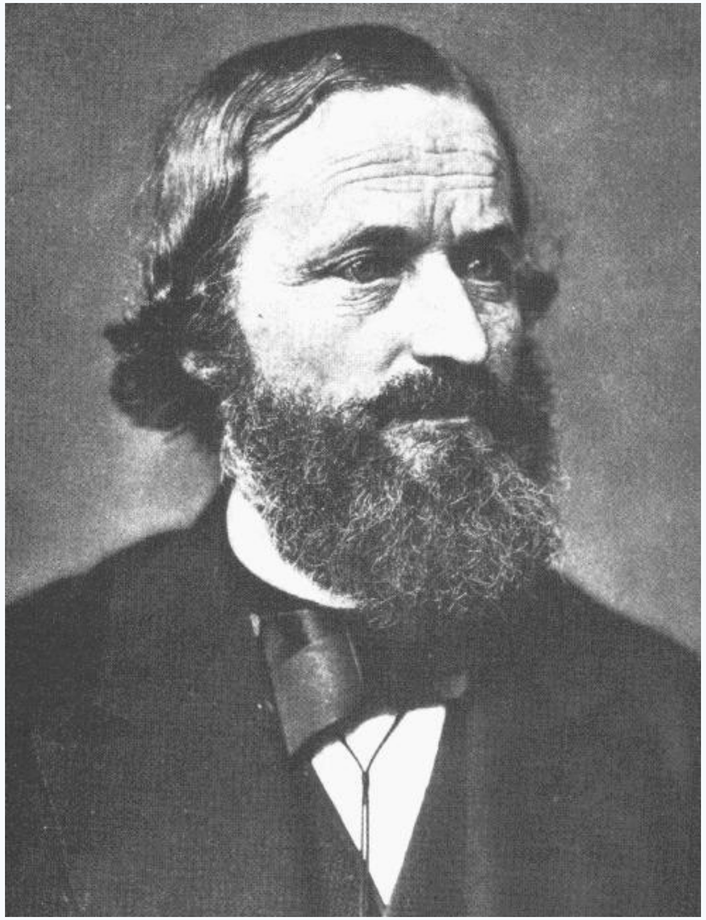


Figure 10. Gustav Kirchoff (Wiki)

- 1824 –1887
- Student of Gauss
- Taught at Berlin, Brausla, and Hiedelberg
- *Vorleschugen uber Matematische Physik*
- Created laws for electrical circuits, spectroscopy, and topology in mathematics

Kirchoff’s First Rule

- A hot and opaque solid, liquid, or highly compressed gas emits a continuous spectrum.

- Example: Light Bulb filament

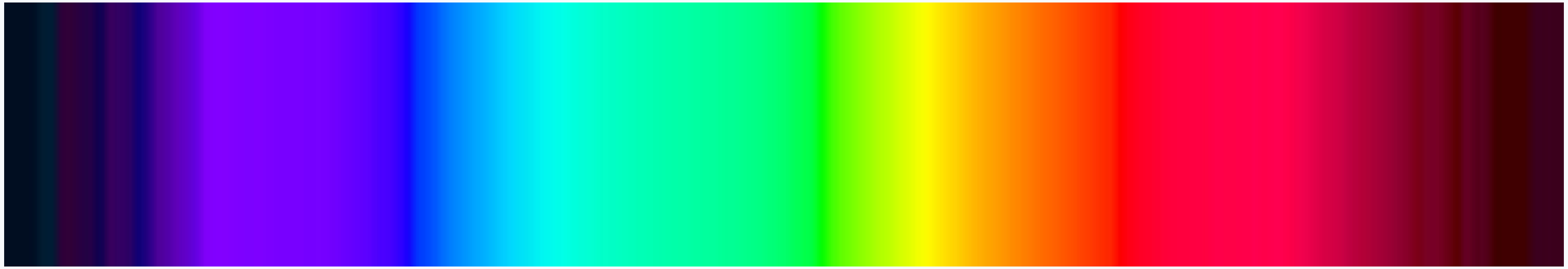


Figure 11. Continuum Spectrum (Wiki)

Kirchoff’s Second Rule

- A hot, transparent gas produces a spectrum of bright lines (emission lines). The number of these lines depend on which elements are present in the gas.

- Example: A neon sign

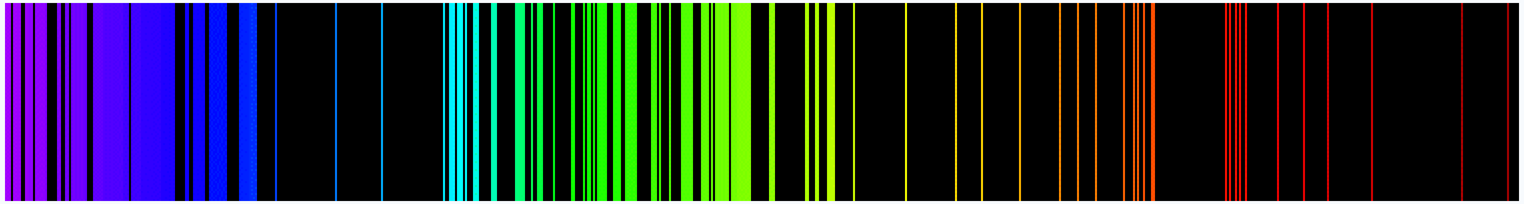


Figure 12 Emission Spectrum (Wiki)

Kirchoff’s Third Rule

- If a continuous spectrum (from a hot, opaque solid, liquid, or gas) passes through a transparent gas at a lower temperature, the cooler gas will cause the appearance of dark lines (absorption lines).
- Example: Light from the Sun.

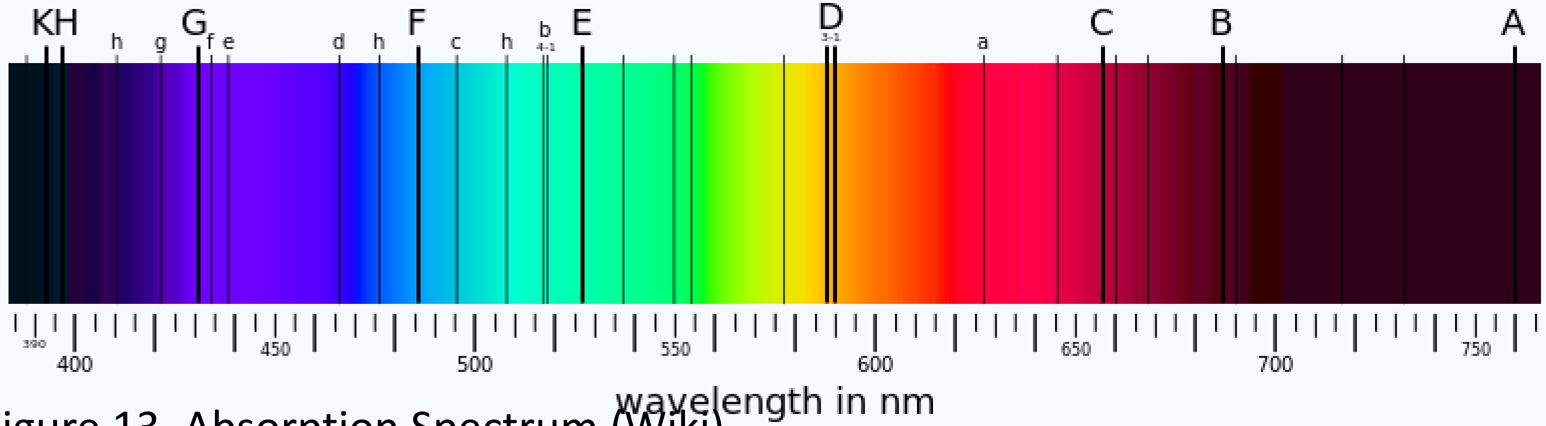


Figure 13. Absorption Spectrum (Wiki)

Wilhelm Wien

- 1864 -1928 A.D.
- Born in Fischhausen, East Prussia
- Studied in Göttingen, Berlin
- Work with Helmhotlz about the diffraction of light off of metal
- Took time off for farm management.

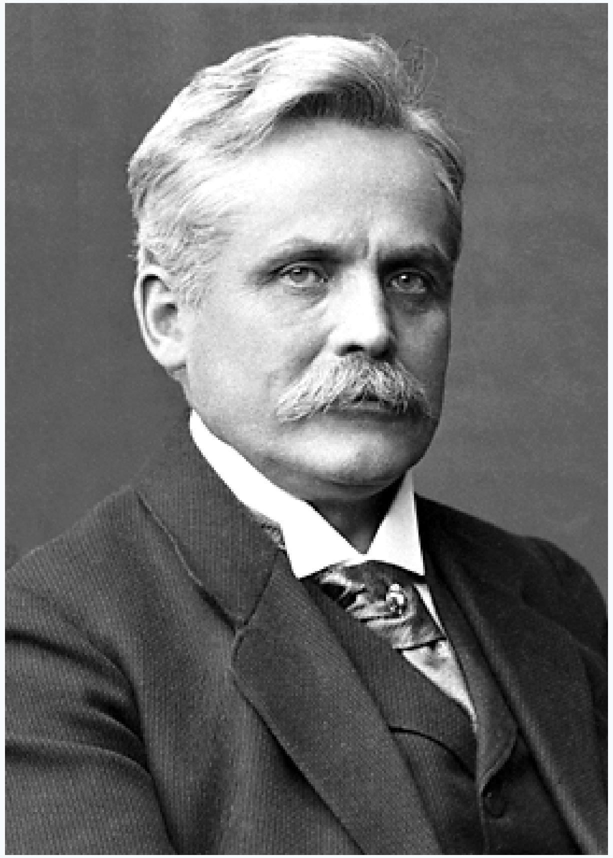


Figure 14. Wilhelm Wien (Wiki)

Max Planck

- 1885 – 1947
- Born in Keil, Germany
- Studied in Munich and Berlin eventually becoming a professor in Berlin.
- Married twice with five children.
- Studied thermodynamics which led him to the study of blackbodies.
- Won the Nobel Prize in 1918

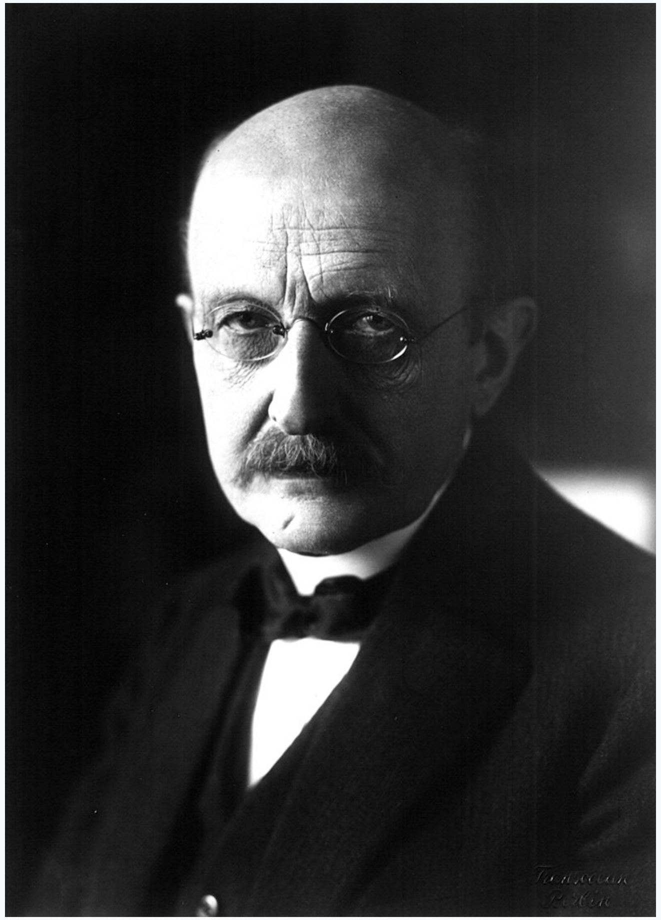


Figure 15. Max Planck (Wiki)

Wien and Planck’s Work

- Separately, Wien and Planck noticed blackbodies emitted specific spectral lines at different temperatures.
- Along with Einstein, Wein noted a relationship of these spectra lines to specific voltages applied to the blackbodies.
- From these observation, a new idea of the quanta was created.

Black Body Radiation

- Studied black, metallic masses and heat these bodies and observed that peak (brightest) wavelength changed with temperature.
- Published in 1883 in Munich
- $T = 2.9x10^{-3} / \lambda_{PEAK}$
- $E=hf$
- Led to the works of Max Planck and J.J. Tomson and the development of atomic theory.

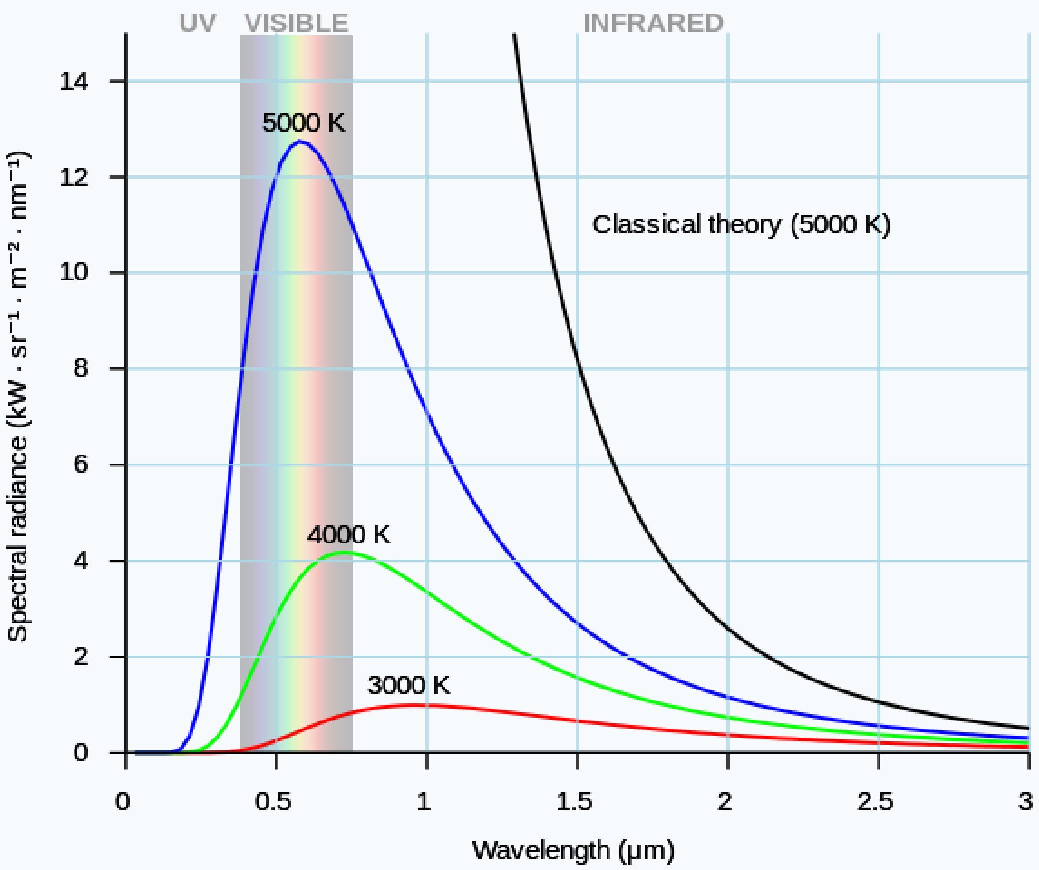


Figure 16. Blackbody Curves (Wiki)

Black Body Example

- If a temperature of a star is 5,700 K, what is its peak wavelength?

$$\lambda = \frac{2.9X10^{-3}mK}{T} = \frac{2.9X10^{-3}mK}{5,700K} = 5.09X10^{-7}m$$

Energy of Light

- What is the energy of the above wavelength?

$$E = hf$$

$$E = (6.6625X10^{-34}Js)(4.567X10^{14}/s) = 3.026X10^{-19}J$$

J.J. Thomson

- 1856 - 1940
- Born in Cheetham Hill, Manchester, England
- Studied and became Master of Trinity College, Cambridge
- Fathered two children
- Both he (1906) and his son (1937) won the Nobel Prize

Figure 17. J.J. Thomson (Wiki)

J.J. Thomson's Experiments

- Thomson wanted to explore the conduction of cathode rays in cathode ray tubes
- He created electric field around the ray tube.
- He noted the charged particles flowed toward the positive terminal indicating they were negatively charged and named these particles electrons.
- Thomson suggested these particles were embedded in an ether like raisins in plum pudding.

Robert A. Milikan

- 1868 -1953
- Studied at Columbia and went to work at University of Chicago
- Won the Nobel in 1923 for his work with electric properties of fluids
- Became one of the founders of the California Institute of Technology

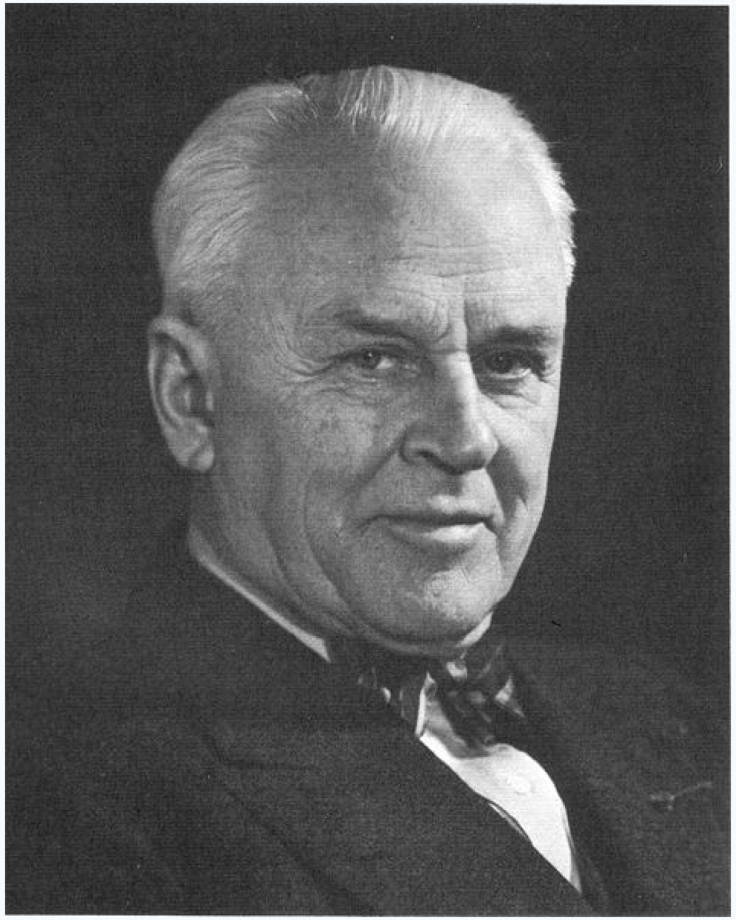


Figure 18. Robert A. Milikan (Wiki)

Milikan’s Experiments

- Charged oil drops were deflected using charged plates
- Thomson had found a q/m, but Millikan used to gravity to confirm this result.
- Showed that charge was quantized.
- $Mass_{electron} = 9.11 \times 10^{-31}$ kg

Other Structures

- The presence of Alpha, Beta and Gamma particles suggested other internal structures in the atom
- Click on the image to see these particles in action.

Ernest Rutherford

- 1871 – 1937
- Studied in New Zealand and worked in Cavendish lab in Cambridge
- Won the Nobel Prize (1907) and was knighted in 1914
- His students discovered the Ionsphere and developed the particle accelerator.

Figure 18. Ernest Rutherford (Wiki)

Rutherford's Experiments

- Focused a beam of alpha particles through a thin sheet of Au (Gold) then detected behind by zinc sulfide that sparked when alpha hit it.
- Most particles went through the sheet of Au, but some were back scattered by a small object, assumed to be a nucleus
- Regions assumed to be 10^{-13} to 10^{-8} cm
- $mass_{proton} = 1.67 \times 10^{-27}$ kg

Rutherford’s Experiment

- Used alpha to break up the nucleus of a N (nitrogen) atom and found 7 discrete unit of charge like the electrons, but positively charged
- Called the particles protons
- Lead to atomic number for each element
- Maxwell put the proton and electron together with the electron orbiting the proton

Niels Bohr

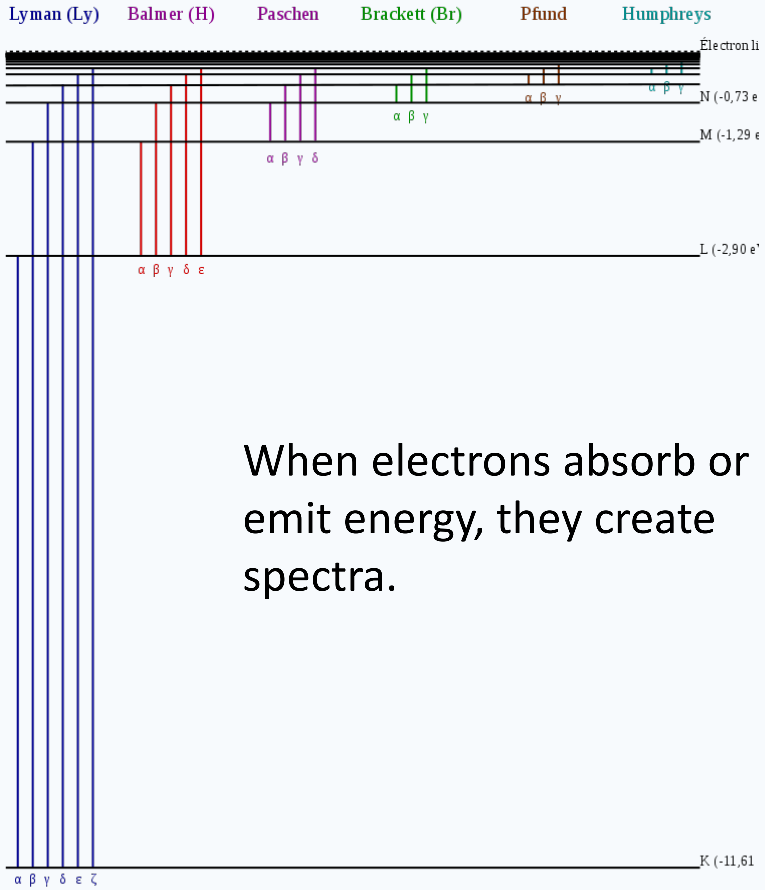
- 1855 – 1962
- Studied at Copenhagen and then joined Rutherford and Thomson at Cambridge
- Returned to Copenhagen and then went to United States to work on the Manhattan Project
- Was a great footballer (soccer) player

Figure 19. Niels Bohr (Wiki)

Bohr's Model of the Atom

- Allowed orbits have angular momentum conserved and angular force corrected
  - $mvr = nh/2\pi$
  - $kq_1q_2/r^2 = mv^2/r$
- Solving the equations simultaneously we get the Bohr radius of 5.29×10^{-11} m
- Stable orbits do not give off radiation.
- Quantum leaps emit or absorb radiation.
- Bohr model worked wonderfully for H, but did not work for higher atoms so we needed a new science, Quantum Mechanics

Results of the Bohr Model of the Atom



When electrons absorb or emit energy, they create spectra.

Figure 20. Atomic Series (Wiki)

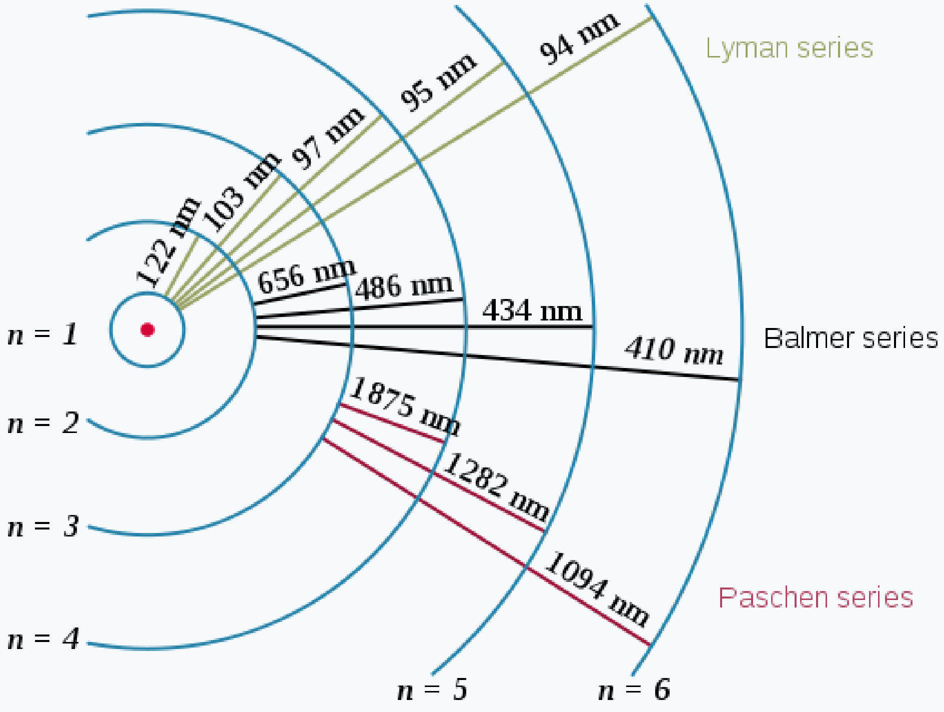


Figure 21. Electronic Orbits in Hydrogen (Wiki)

Erwin Schröndinger

- 1887 - 1961
- Studied in Austria and worked in Oxford, Ireland, and Austria
- Won the Nobel Prize (1933)
- His work with quantum mechanics inspired many to find similar structure in biological life, i.e. DNA

Figure 22. Erwin Schröndinger (Wiki)

Quantum Mechanics

- All particles, proton and electrons, are considered matter waves
- All matter waves have a range of positions and velocities and one must observe the particle to determine these values.
- Some values are incompatibly observed such are position and velocity or energy and time, i.e. the Heisenberg Uncertainty Principle.
- Albert Einstein and Max Planck both wanted to understand why this worked so they studied light.

Quantum Mechanics (cont.)

- Quantum Mechanics Model
  - Fuzzy versus Strong
    - Hiesenberg Uncertainty Principle
  - Distance, orbital, orientation, and then direction
  - Principle quantum number: $n = 1,2,3\ldots$
  - Angular momentum: $l = 0,1,\ldots(n-1)$
  - Magnetic quantum number: $m_l = -l\ldots+1$
  - Spin number: $s = -1/2,+1/2$
  - Pauli Exclusion Principle

Electron Configuration

Energy Level	Orbital	Number of e^-	Number of e^-/level
1	0,s	2	2
2	0,s	2	
	1,p	6	8
3	0,s	2	
	1,p	6	
	2,d	10	18
4	0,s	2	
	1,p	6	
	2,d	10	
	3,f	14	32

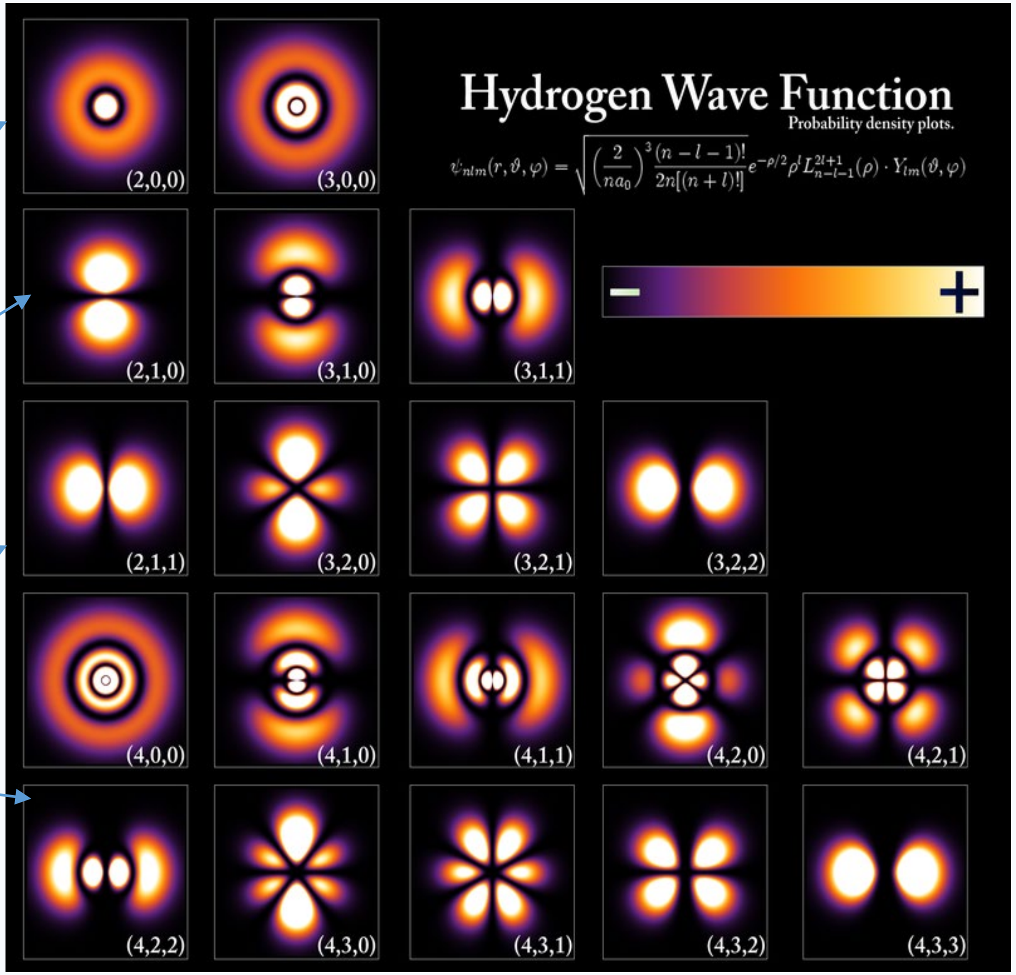
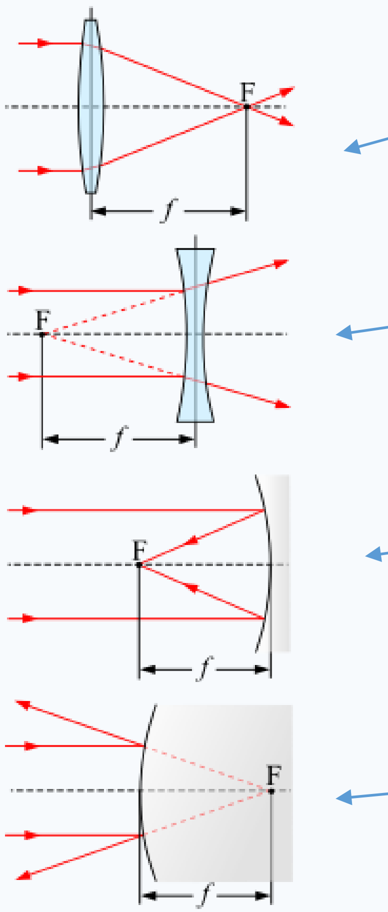


Figure 23. Electronic Configurations for Hydrogen (Wiki)

Optical Systems

- Refraction: Lenses, Fiber Optic
- Reflection: Mirrors
- Diffraction: Mirrors, Gratings
- Dispersion: Mirrors, Lenses, Prisms
- Interferometers, Spectrometers combines all these proccesses

Lenses and Mirrors



- Convex Lens
- Concave Lens
- Concave Mirror
- Convex Mirror

Figure 24. Lenses and Mirrors (Wiki)

Interferometer and Spectrometer Complex Optical Systems

Interferometer

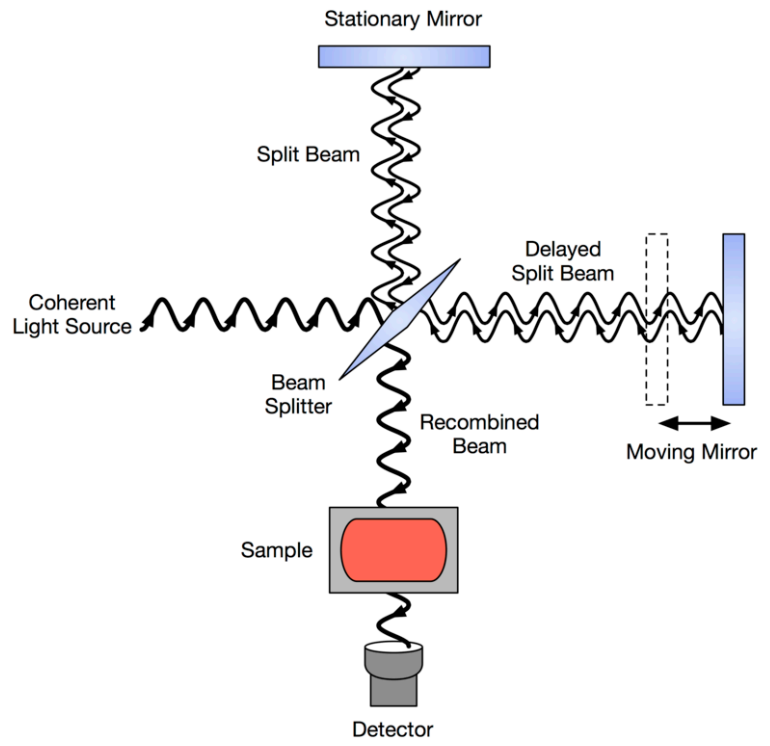


Figure 25. Interferometer (Wiki)

Spectrometer

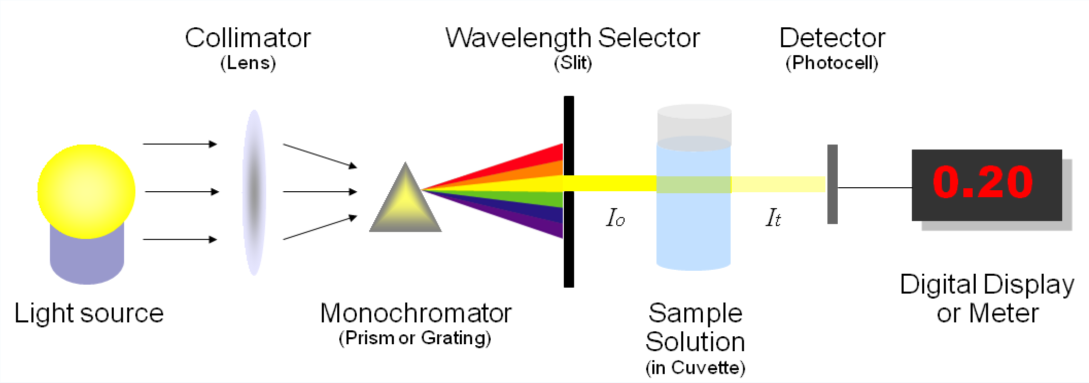


Figure 26. Spectrometer (Larson, 2105)

George Ellery Hale

- 1868 – 1938
- Studied at MIT, Harvard, and Berlin
- Appointed director at Kenwood Observatory, Beloit, and was professor at University of Chicago
- Father of the Modern Telescope; built at Mts. Wilson and Palomar and Yerkes
- Suffered psychological problems much of life

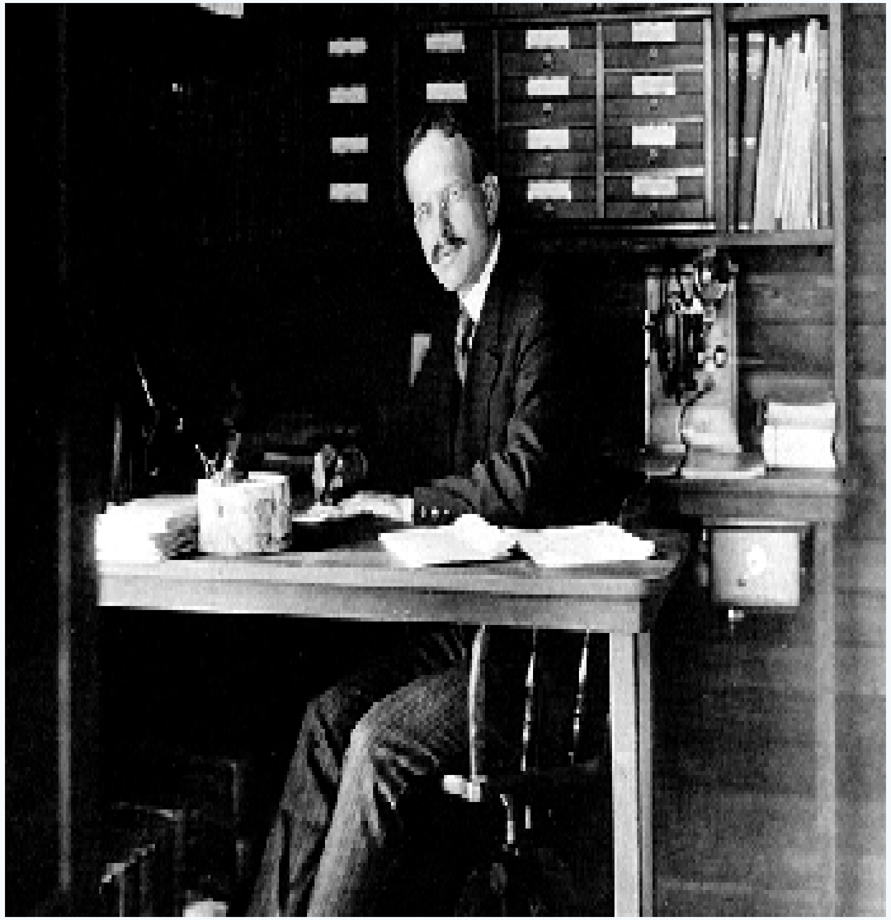


Figure 27. George Ellery Hale (Wiki)

Refracting Telescopes

- Developed by the Dutch and Galileo
- Has two lenses; main: Objective, secondary: Eyepiece
- Largest: Yerkes Observatory @ 40 inches

Figure 28 Chamberlain Observatory, University of Denver, Rolando Branly, 2011

Reflecting Telescope

- Developed by Isaac Newton
- Has a primary mirror, possibly a secondary mirror, and lens for an eyepiece
- Largest: Keck @ 10 meters

Figure 29. Lowell Observatory, Arizona, Sean Casey, 2011

Telescopic Properties

- Light Gathering Power
  - LGP= $(D_1\backslash D_2)^2$
- F-ratio
  - f-ratio=f\D
- Resolution
  - TR=$(2.52X10^6)(\lambda/D)$
- Magnification
  - MP=$f_o\backslash f_e$

Telescopic Properties.

We have two telescopes; one with a 10 meter diameter and one with 0.9 meter diameter. How much is the light gathering power greater in the 10 meter than the 0.9 meter?

$$D_1 = 10\,m$$

$$D_2 = 0.9\,m$$

$$LGP = \left(\frac{D_1}{D_2}\right)^2 = \left(\frac{10m}{0.9m}\right)^2$$

$$LGP = 123X$$

Kitt Peak National Observatory

Figure 30. Kitt Peak National Observatory (Fix, 2004)

Types of Telescopes

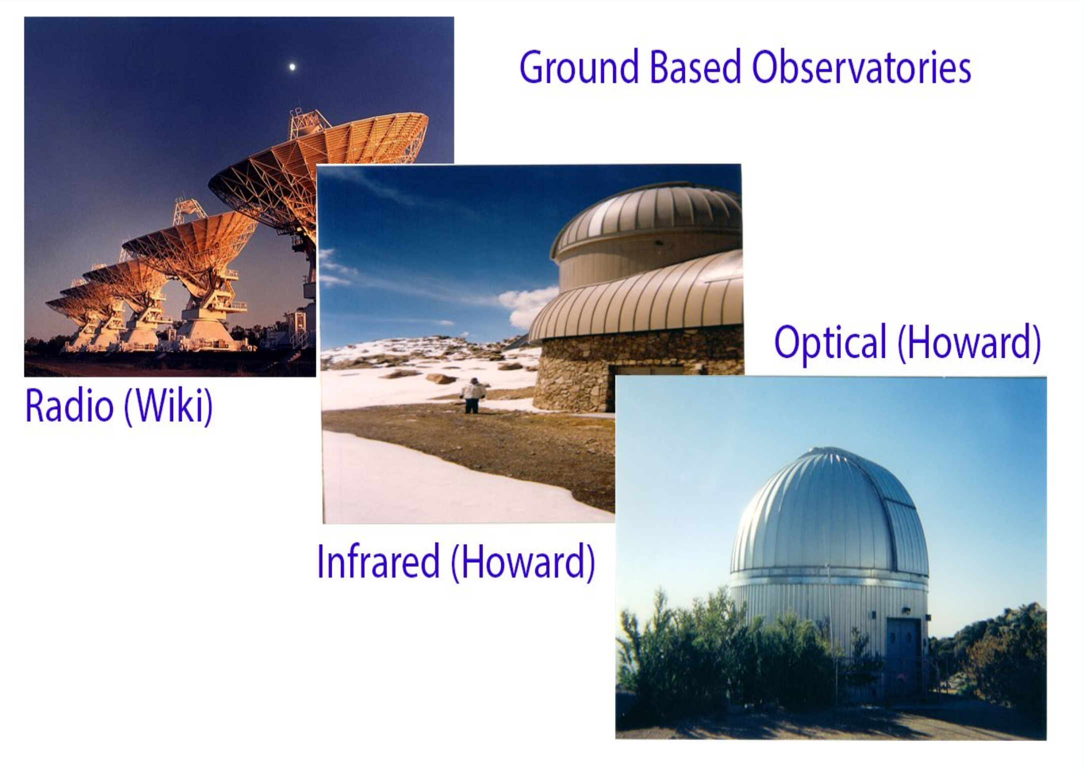


Figure 31. Ground Based Observatories (As Listed)

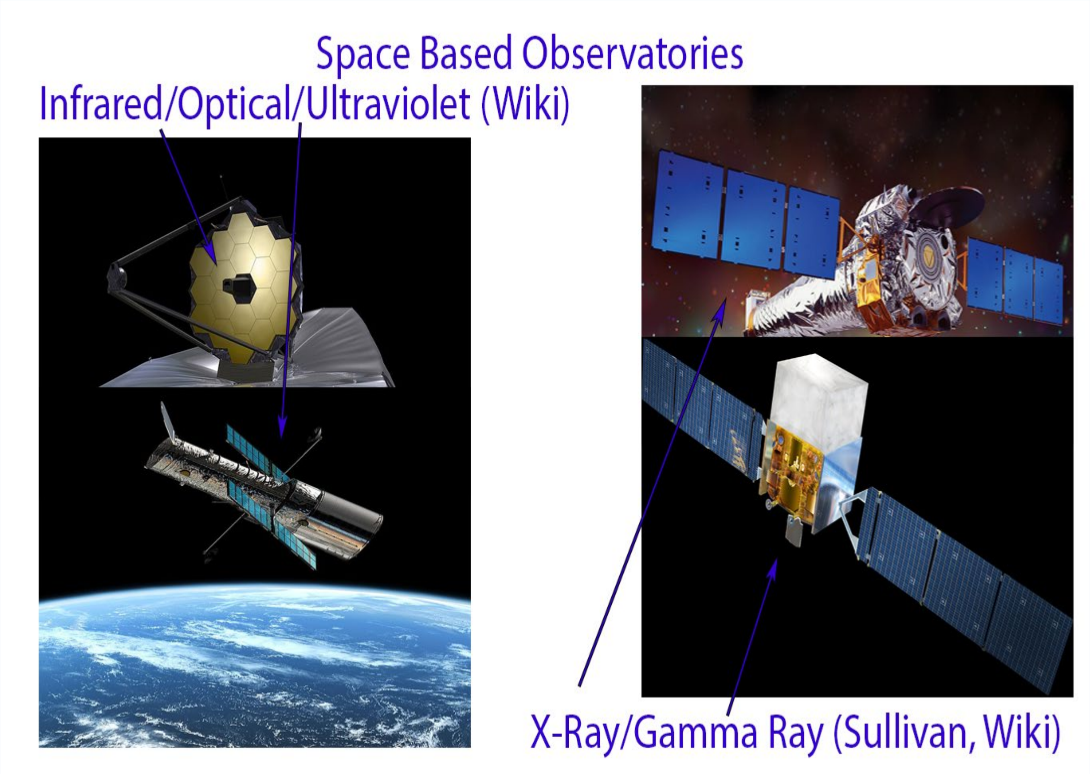


Figure 32. Space Based Observatories (As Listed)

Challenges

- Seeing
  - Limits on LGP and resolution
- Atmospheric Absorption
  - Limits on resolution and wavelengths
- Space Astronomy
  - Limits on which objects you can observe
- And…

Light Pollution

Figure 34. A Nighttime picture of United States (Fix, 2004)

CCD/CMOS Cameras and Astronomical Images

- We use mainly Charged Coupled Devices (CCD)/ Complementary Metal-Oxide-Semiconductor (CMOS) cameras to obtain Astronomical Images
- To create an analytical observation we need three calibration images: bias, dark, and flat.
- Click on the image to see a playlist describing these cameras and the processes to processing these image.

Book/Course Image References

- Fix, J. D. (2004) *Astronomy: Journey to the Cosmic Frontier,* New York, McGraw-Hill Higher Education.
- Ion, D. (2014) Retreived from:http://science.sbcc.edu/physics/flash/2%20slit%20interference.html
- Larson, D (2015) *Spectrophotometry* Retreived from:
  http://chemwiki.ucdavis.edu/Physical_Chemistry/Kinetics/Reaction_Rates/Experimental_Determination_of_Kinetcs/Spectrophotometry
- Moxon, E. (2001) *Electromagnetic Radiation* Retrieved from: http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/
- Sullivan, Robert (2017), Chandarsehkar Telescope, Retrieved from:
  https://www.flickr.com/photos/my_public_domain_photos/35337940272

Wiki Commons/Wikipedia Image References

- Absorption Spectrum: "Fraunhofer lines" by Fraunhofer_lines.jpg: nl:Gebruiker:MaureenVSpectrum-sRGB.svg: PhroodFraunhofer_lines_DE.svg: *Fraunhofer_lines.jpg: Saperaud 19:26, 5. Jul. 2005derivative work: Cepheiden (talk)derivative work: Cepheiden (talk) - Fraunhofer_lines.jpgSpectrum-sRGB.svgFraunhofer_lines_DE.svg. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Fraunhofer_lines.svg#/media/File:Fraunhofer_lines.svg
- Atomic Series: „Spectral lines of the hydrogen atom“ von Régis Lachaume - Made by myself. Lizenziert unter Gemeinfrei über Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Spectral_lines_of_the_hydrogen_atom.svg#/media/File:Spectral_lines_of_the_hydrogen_atom.svgor
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- Electron Configurations: "Hydrogen Density Plots" by PoorLeno (talk) - the English language Wikipedia (log).Original text: I created this work entirely by myself. References:Forinash, Kyle. Hydrogen W Simulation. Indiana University Southeast. Retrieved on 2008-12-18.Tokita, Sumio; Sugiyama, Takao; Noguchi, Fumio; Fujii, Hidehiko; Kobayashi, Hidehiko (2006). "An Attempt to Construct an Isosurface Having Symmetry Elements". Journal of Computer Chemistry, Japan 5 (3): 159–164. DOI:10.2477/jccj.5.159.. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Hydrogen_Density_Plots.png#/media/File:Hydrogen_Density_Plots.png
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