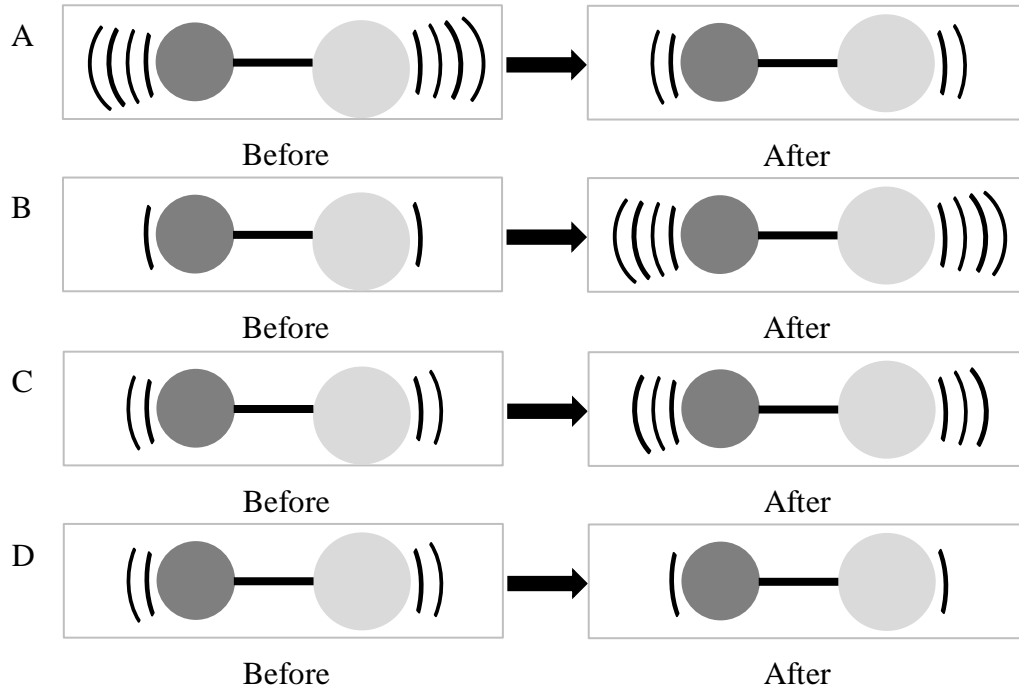


Rotation, Vibration, and Synchrotron Radiation – Astronomical Interactions of Light and Matter

Lecture-Tutorial

Part I: Light and Molecules

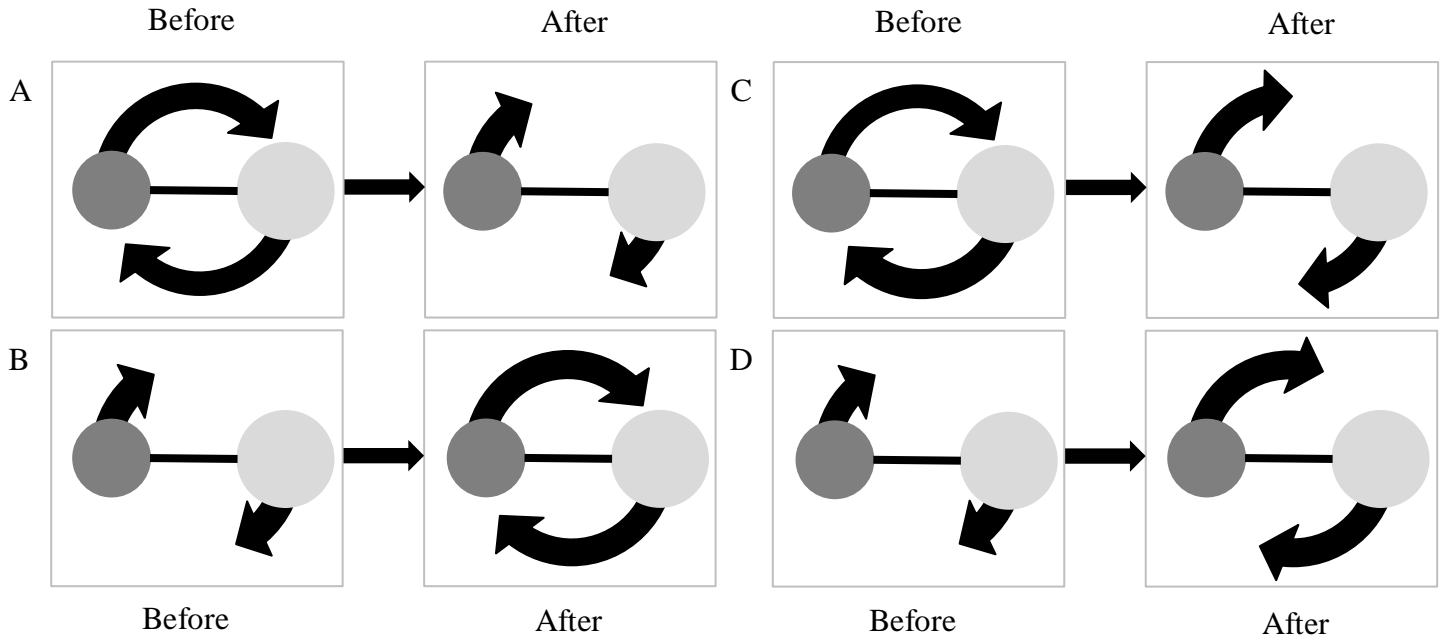
A molecule can change its vibrational energy state by emitting or absorbing an infrared photon. In each of the four cases shown below (A-D), a molecule is shown transitioning between two different energy states depending on whether the molecule absorbed or emitted a photon.



- 1) Which of the cases (A-D) shown above correspond with the absorption of light and which correspond with the emission of light? Draw in a squiggly arrow representing a photon with the appropriate direction for each case (A-D).
- 2) In which case was a photon with the longest wavelength absorbed? Explain your reasoning.
- 3) In which case was a photon with the greatest energy emitted? Explain your reasoning.

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A molecule can change its rotational energy state by emitting or absorbing a radio photon. In each of the four cases shown below (A-D), a molecule is shown transitioning between two different energy states depending on whether the molecule absorbed or emitted a photon.



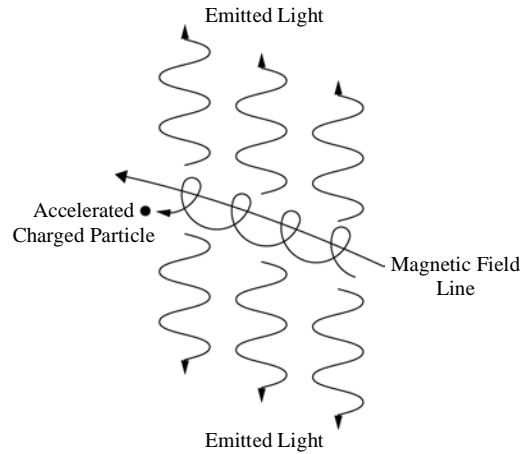
- Which of the cases (A-D) shown above correspond with the absorption of light and which correspond with the emission of light? Draw in a squiggly arrow representing a photon with the appropriate direction for each case (A-D).
- In which case was a photon with the shortest wavelength emitted? Explain your reasoning.
- In which case was a photon with the least energy is absorbed? Explain your reasoning.
- Complete the sentences in the following paragraph by using the following words/phrases (note that each word/phrase is only used once):
 - radio
 - visible and ultraviolet
 - infrared

Because only a small amount of energy is needed to change a molecule's rotational energy state, the emission and absorption lines produced by rotating molecules are typically at _____ wavelengths. Making a molecule change vibrational energy states requires slightly more energy, so the emission and absorption lines produced by vibrating molecules are typically at _____ wavelengths. Making an electron change orbital energy levels in an atom requires even more energy, so the emission and absorption lines produced by electron transitions are typically found at _____ wavelengths.

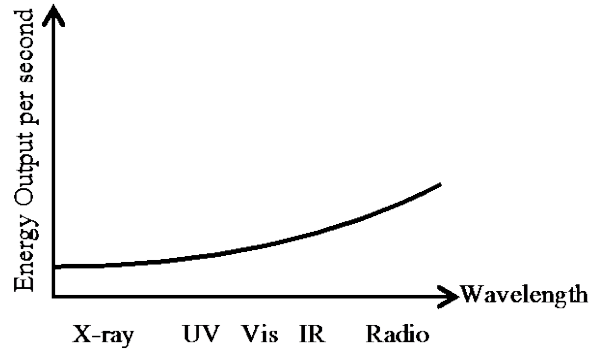
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Part II: Synchrotron Radiation

When a charged particle (an electron or proton) is forced to spiral around a magnetic field, the charged particle undergoes an acceleration (because it is constantly changing the direction of its motion) that causes light to be emitted by the charged particle. We call the light that is emitted by this process **synchrotron radiation**. The figure below shows the physical process that produces synchrotron radiation.



The graph below shows the amount of energy given off each second for each wavelength of light for an object emitting synchrotron radiation.



- 8) At which wavelength(s) does synchrotron radiation emit light?

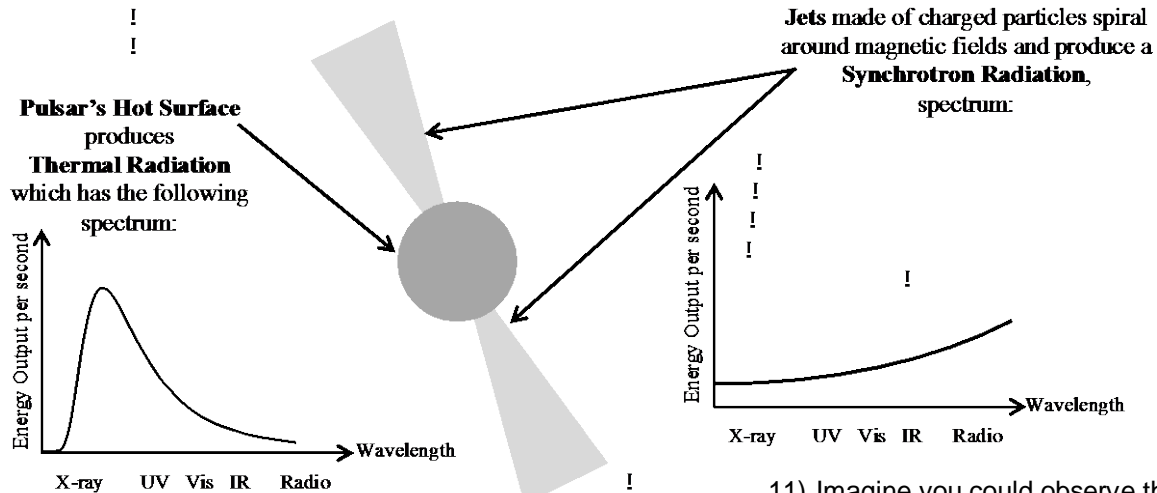
- 9) At which wavelength does synchrotron radiation emit the most energy per second?

- 10) Is it possible to detect synchrotron radiation with an X-ray telescope? Explain your reasoning.

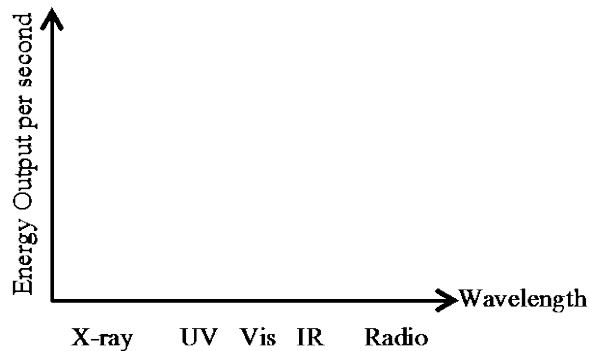
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The figure below shows a pulsar, which is the remnant of a dead massive star. A pulsar has a strong magnetic field, around which jets of charged particles spiral, producing synchrotron radiation. The hot surface of a pulsar produces thermal radiation with a spectrum that peaks in X-rays.



11) Imagine you could observe the pulsar at all wavelengths of light, from X-rays to radio. On the graph below, sketch the spectrum of light you would detect that results from the **combination** of the synchrotron radiation from the pulsar's jets and the thermal radiation from the pulsar's surface.



12) On the graph you made in Question 11, circle the wavelengths at which you receive more light from the synchrotron radiation from the pulsar's jets than thermal radiation from the pulsar's surface. Put a box around the wavelengths at which you receive more light from the thermal radiation from the pulsar's surface than synchrotron radiation from the pulsar's jets.

13) Which one type of light is best for observing the pulsar's synchrotron radiation? Explain your reasoning.

Lecture-Tutorial

Part III: Real Telescopes and Observations

Here are four real telescopes:

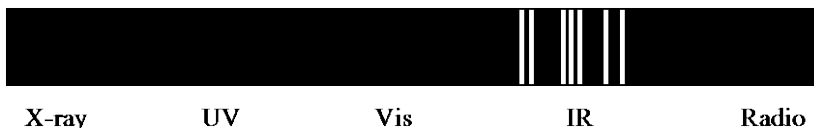
- The Atacama Large Millimeter Array (ALMA) is a radio telescope located in Chile
- The Chandra X-ray Observatory is an X-ray telescope located in space, orbiting the Earth
- The Spitzer Space Telescope is an IR telescope located in space, orbiting the Sun
- The Galaxy Evolution Explorer (GALEX) is a UV telescope located in space, orbiting the Earth

Use the above information to help answer the following questions.

14) Astronomers, trying to understand the origins of life, observe rotating organic molecules in nebulae.

- a) Rotating organic molecules produce a(n) _____ (circle one of the following three choices: *synchrotron / thermal / emission or absorption line*) spectrum.
- b) Which telescope listed above would be best to detect the light from rotating organic molecules in nebulae? Explain your reasoning.

15) Here is a spectrum of light:

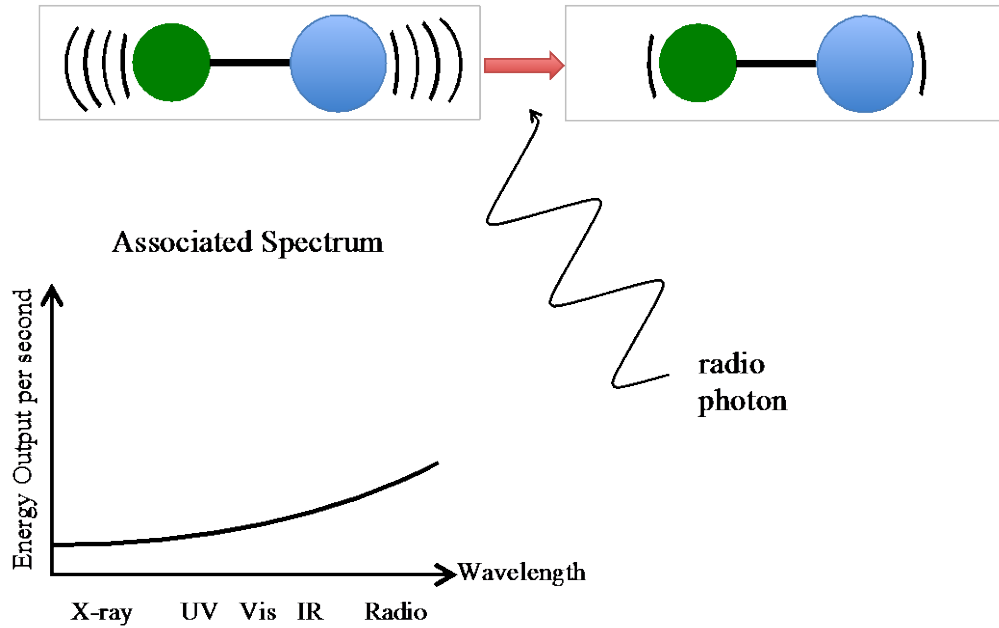


- a) This spectrum is produced by ____ (circle one of the following five choices).
- the hot surface of a pulsar
 - charged particles spiraling around a magnetic field
 - electrons changing energy states
 - molecules changing vibrational states
 - molecules changing rotational states
- b) Which telescope listed above would you use to detect this spectrum?

16) Black holes have extremely large magnetic fields that cause charged particles to accelerate away from the black hole, creating jets of material. The charged particles spiral around the magnetic field and emit light as they are ejected. Is it *possible* for an astronomer to detect the light from a black hole jet if she uses the Chandra X-ray Observatory? Explain your reasoning.

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A molecule changes its vibrational energy state as shown in the figure below.



17) Which of the following are represented incorrectly: the direction of the photon, the energy of the photon, and/or the associated spectrum of light? Explain your reasoning.

18) Correct the graphs and drawings in Question 17 to fix all of the errors you identified with the direction of the photon, the energy of the photon, and/or the associated spectrum of light.