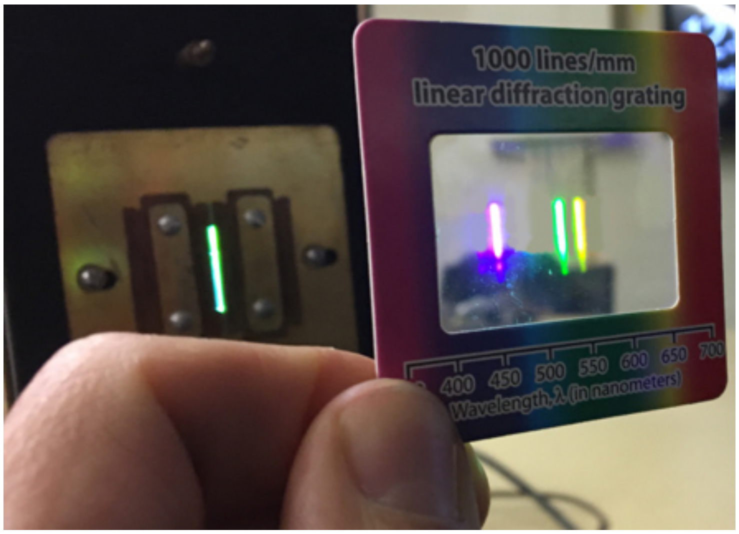
Practice question related to

- **The wave nature of electrons**
- **Energy level diagrams for atoms, molecules and solids**

1. Spectroscopy



Sketch a graph of spectral intensity, $I_\lambda(\lambda)$, for the atomic vapor lamp shown in the photo.

2. Waves on a string

Consider the wave equation for the y-displacement of a string that is stretched out in the x direction:

$$\frac{\partial^2 y}{\partial x^2} = \frac{\mu}{T}\frac{\partial^2 y}{\partial t^2}.$$

One possible solution to this differential equation is

$$y(x, t) = y_0 * \sin(2\pi f t)\sin(2\pi x/\lambda)$$

where y_0 is a constant amplitude, f is a constant frequency and λ is a constant wavelength.

What relationship between f and λ is required so that $y(x, t)$ satisfies the differential equation?

3. Bugle

a) Which sound waves (i.e. what wavelengths) can satisfy the boundary conditions of a bugle? Assume there is a pressure anti-node at the mouthpiece, a pressure node at the bell, and the length of the instrument is 1 meter.

b) Draw a frequency level diagram for the first 4 allowed frequencies.

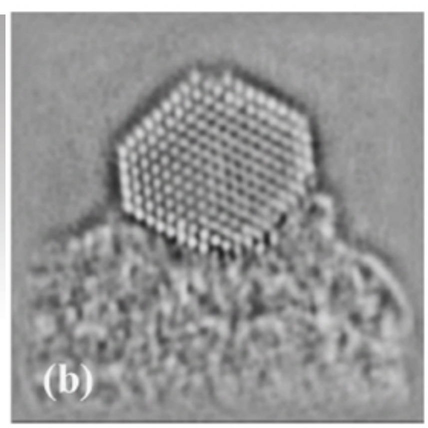
4. de Broglie wavelength for the electrons in atoms

Electrons that are orbiting a nucleus (i.e. electrons that are part of an atom) have a de Broglie wavelengths of the order 10^{-10} m.

a) Find the order of magnitude for the momentum of an electron that is orbiting a nucleus.

b) Find the order of magnitude of the kinetic energy of an electron that is orbiting a nucleus (give you answer in units of eV).

5. Transmission electron microscopy



A transmission electron microscope can capture image of individual atoms. A beam of electrons passes through the sample and is collected by a lens to form an image of the sample. To see individual atoms, the de Broglie wavelength needs to be 10^{-10} m. How fast do the electrons need to travel to get atomic resolution?

6. deBroglie wavelength of a macroscopic object
What is the deBroglie wavelength of a 10-gram bullet traveling at twice the speed of sound?

7. Hydrogen atom
The allowed energy levels for an electron orbiting a proton are given by

$$E_n = -13.6 \text{ eV}/n^2.$$

Calculate the visible wavelengths of light that could be absorbed or emitted by the hydrogen atoms.

8. Chlorophyll
The allowed energy levels for the last 12 electrons in the tail of chlorophyll molecule are given by (approximately)

$$E_n = -E_0 + h^2n^2/8mL^2,$$

where E_0 is an energy constant, the tail of the chlorophyll is 12 bonds long and the C-C bond length is 0.14 nm.

a) Draw the energy level diagram for the first 8 energy levels. Label the energies in eV.

b) Calculate the lowest photon energy that can be absorbed by this system.

c) Calculate the second-to-lowest energy that can be absorbed.

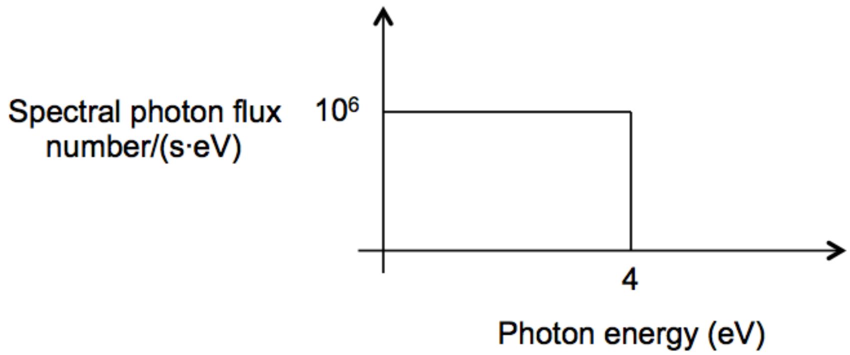
9. Photovoltaics
Gallium arsenide (GaAs) is a semiconductor with a band gap of 1.4 eV. Compare a thick piece of pure GaAs to a thick piece of pure silicon.

a) Which of the two semiconductors will absorb a greater fraction of the sun's light?

b) True or false: The material that absorbs more sunlight will also have the highest theoretical maximum efficiency for solar energy conversion. (explain your answer)

10. A ridiculous question (but good practice)
How many electronVolts in 1 kiloWattHour?

11. Photovoltaics



The graph shows the distribution of photon energies for a light source that emits 4 million photons per second. In the energy range 0 – 0.1 eV, there are 10^5 photons per second. In the energy range 0.1 – 0.2 eV, there are 10^5 photons per second, and so forth.

a) Calculate the optical power output from this light source (this is an integration problem).

b) A photovoltaic cell is set up so that it absorbs all the light from this source. Estimate the maximum electrical power output of the photovoltaic cell (assume an arbitrary band gap, E_g).

c) Find the optimal band gap for harvesting energy from this light source.