PH315 Physics of Contemporary Challenges Winter 2019

Student ID number ____________________ Name ________________________________

(Write neatly!) (First and Last)

Practice Final Exam

This set of practice questions is longer than the actual final.
The real final will have about 30% of material from first half of course, 70% from second half

Write your answers in the space underneath each question. If when writing in pencil, make sure it is dark enough (ask the instructor if you are unsure). If you need extra paper, please ask.

You may use any information on your note card (both sides of an 8.5 x 11" page). Otherwise, the exam is closed book.

You may use a calculator. Alternatively, full credit will be given if you use mental arithmetic and make a reasonable effort to get a final answer within ±10%. For example, π can be rounded to 3 if you are using mental arithmetic.

State any assumptions you make to solve the problem. Show the mathematics that you use to solve the problem. Show enough working so that the grader doesn't over-penalize a small mistake. Show units when working with the numerical values of physical quantities. Because time is limited, you are not required/expected to write very many words explaining of your reasoning.

You will lose points if your final answer has a ridiculous number of significant figures. Final answers should have no more than 2 or 3 significant figures, unless otherwise stated.

Very big or very small numbers must be expressed in scientific notation (for example, 1.2×10^6). You will lose points if you use decimal notation for final answers that are greater than 10^6 or less than 10^{-3}. You will also lose points if you use E-notation (for example, do not write 1.2E6).

If a question asks for a quantitative answer, do not expect partial credit for a conceptual answer.

You may ask me any questions you wish. I may or may not answer.

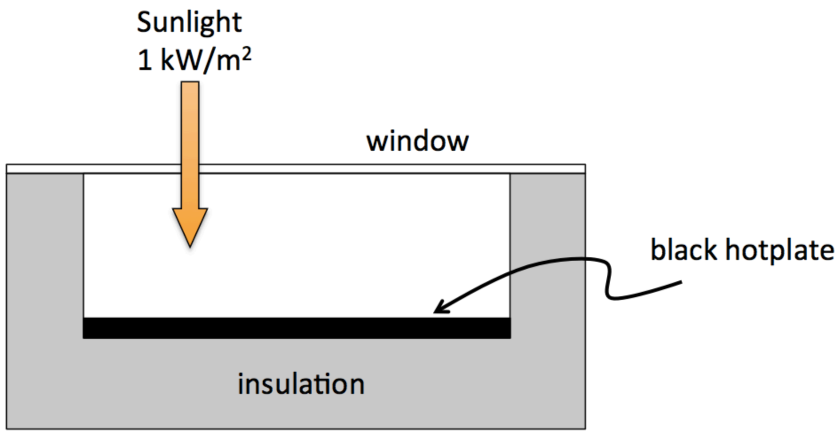
1. Lifetime of the Sun

Make a Fermi estimate of the lifetime of the Sun, assuming that the Sun's rate of energy output stays constant throughout its lifetime (4×10^{26} W). Give your answer in years.

Useful info: The Sun began with about 2×10^{30} kg of hydrogen atoms. Each proton can release a total of 8 MeV as it becomes bound to other nucleons via the strong force. Only the core of the Sun (10% of the total mass) gets hot enough for nuclear fusion to occur. Therefore, the total nuclear fuel is about 2×10^{29} kg of hydrogen atoms.

2. Solar oven

Consider the following design for an oven. The oven is designed to cook food using only the energy from sunlight. The black hotplate absorbs 100% of the incident sunlight. The insulation (shaded gray) does not transmit any light or heat. The only way for heat to escape is through the glass window.



a) Assume that the glass window is fully transparent to all wavelengths of light and the only way for heat to escape is via blackbody radiation. In thermal equilibrium, what is the temperature of the black hotplate? Compare your answer to the boiling point of water (the boiling point of water is 373 K).

b) Now we change to a different type of glass window. This new glass window is transparent to sunlight (transparent to visible wavelengths), but absorbs all of the blackbody radiation emitted by the black hotplate (opaque to infra-red wavelengths). After establishing thermal equilibrium, what is the temperature of the black hotplate?

3. Electron energy levels

The energy of the electron in an isolated hydrogen atom is given by

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

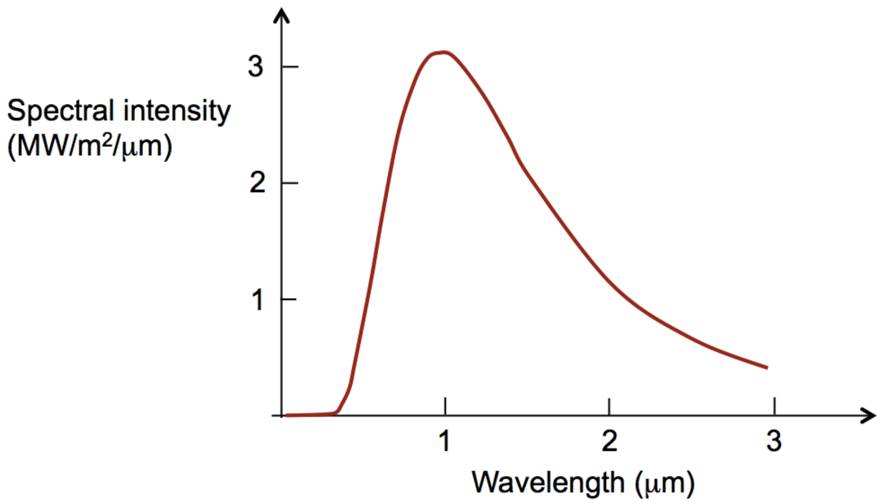
where n is a non-zero positive integer. Consider the photon emitted when the electron transitions from a level with $n > 4$ to a level with $n = 4$. Show that there is no such transition that produces a photon with a visible wavelength.

4. Power spectrum

The data table below shows the power spectrum of a light emitting diode (LED) in the relevant range of wavelengths. Use numerical integration (a Riemann sum) to estimate the total power emitted by this LED.

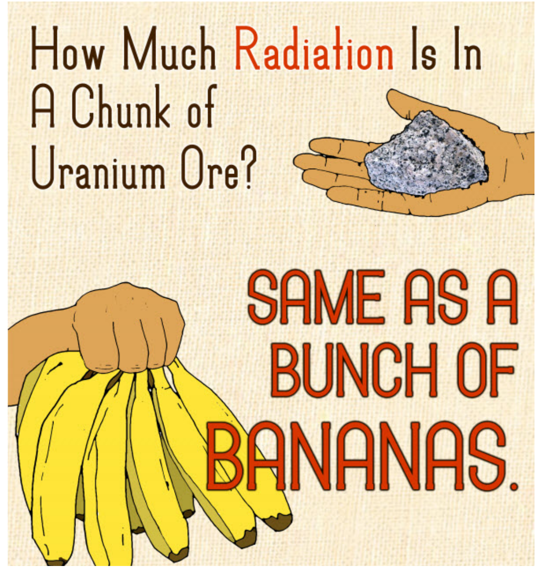
λ (nm)	Spectral power (mW/nm)
520	0
530	2
540	8
550	10
560	8
570	2
580	0

5. Stellar spectrum



The spectral intensity shown above was determined for the surface of a nearby star. What is the temperature on the surface of this star?

5. Nuclear physics (12 pts)



I'd like to consider the poster image with some healthy skepticism.

The radioactivity of a banana comes from the isotope potassium-40. The mass of a peeled banana is about 100 g. The banana contains about 450 mg of potassium, of which about 50 μg is potassium-40.

For uranium ore, I'll make some simplifying assumptions. Assume that 99% of the mass is uranium-238, 1% of the mass is uranium-235 and there are no other radioactive isotopes in the ore.

a) Calculate the activity (decays per second) from the banana.

b) Calculate the activity (decays per second) of 100 g of uranium ore (using my simplifying assumptions).

Half-life data:

- Uranium-238 half-life is 4 billion years.
- Uranium-235 half-life is 0.7 billion years.
- Potassium-40 half-life is 1.25 billion years.

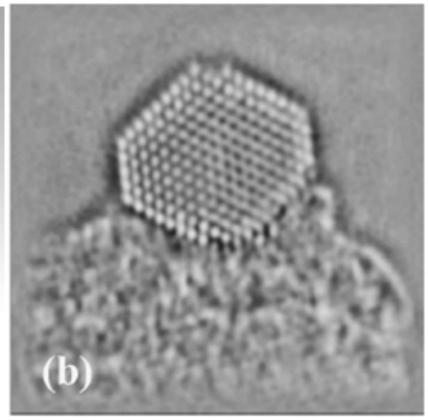
Note: For a full comparison of bananas and uranium ore, I'd have to account for additional factors such as the type of radiation and whether I eat the samples.

6. The planet Mercury

- Mercury has no atmosphere and the surface of Mercury absorbs 93% of the incident sunlight.
- Mercury is 58,000,000 km from the Sun.
- The radius of the Sun 695,000 km.
- The surface of the Sun has a temperature 5700 K.

Use the facts listed above to estimate the temperature on the surface of Mercury. Please assume the planet is spinning fast enough so there is a uniform temperature across the entire surface.

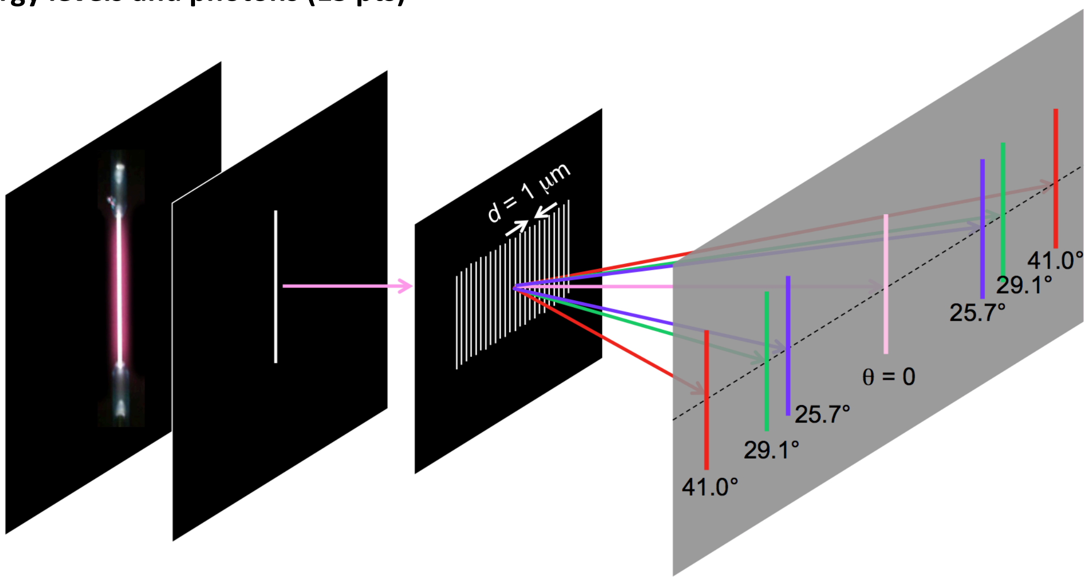
7. Transmission electron microscopy



A transmission electron microscope can capture images 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 less than 10^{-10} m.

The microscope accelerates electrons to have sufficient velocity to image with atomic resolution. How much kinetic energy should the microscope give each electron in the beam? Express your answer in eV.

8. Energy levels and photons (15 pts)



The Figure shows a diffraction experiment performed using a hydrogen vapor lamp and a diffraction grating with 1000 lines per mm.

a) Use the experimentally measured angles to calculate the wavelengths of light that are emitted from the lamp.

b) The energy levels for an electron orbiting a proton are calculated by theory to be $E_n = -13.6\ \mathrm{eV}/n^2$.

(i) Draw an energy level diagram for an electron orbiting a proton.

(ii) Verify that theory predicts the experimentally measured wavelength corresponding to 41.0°.

9. Solar power Fermi estimate

What fraction of Oregon must be covered with solar panels to generate all of the state's energy needs during the winter months? I'm looking for a percentage.

Useful numbers:

- The size of Oregon:

- The average solar intensity in Oregon in January is 1.5 kWh per day per m^2.
- Energy consumption is about 200 kWh per day per person.
- Oregon's population is about 4 million people.
- Commercial solar cells are about 20% efficient.