

NORTHERN ILLINOIS UNIVERSITY

PHYSICS DEPARTMENT

Physics 283 – Modern Physics

Fall 2026

Problem Set #7

Problem Set Due: Thurs., Oct. 29, 2026

Read Krane: Chapter 7.1-7.8

1. **OpenStax University Physics Vol. 3: Section 1.7:** Problem 64
2. **OpenStax University Physics Vol. 3: Section 1.7:** Problem 65
3. **OpenStax University Physics Vol. 3: Section 2.1:** Problem 26 (see solution to #27)

4. **Krane: Problem 20** **page 234** (just show calculation)
5. **Krane: Problem 21** **page 234** (just show calculation)
6. **Krane: Problem 24** **page 234** (sketch energy level diagram)
7. **Krane: Problem 26** **page 234** (sketch energy level diagram)
8. **Krane: Problem 27** **page 234** (sketch energy level diagram)

Take home Quiz #2 extension
worth 50 points on Quiz #2
(open book/open internet problem)

Show all your work. Do not skip any algebra or
calculus steps—otherwise you will be penalized.

See next page:

9. The Virial Theorem: Recall from your mechanics class where you learned that the conservation of energy relation is

$$E = K + U$$

where E = total energy, K = kinetic energy, and U = potential energy. Then the expectation value (or average) of the total energy can then be written as

$$\langle E \rangle = \langle K + U \rangle = \langle K \rangle + \langle U \rangle.$$

This is the *Virial Theorem*. Show that the expectation value of the kinetic energy for the 1s state of hydrogen (read Section 7.7 of Krane) is

$$\langle K \rangle = \frac{\hbar^2}{2ma_0^2}.$$

Does your expression for the kinetic energy have the right units?

10. The Schrodinger equation for a hydrogen-like atom:

The Schrodinger equation for a hydrogen-like atom can be written in the form

$$-\frac{\hbar^2}{2m} \frac{d^2 u}{dr^2} + \frac{\ell(\ell+1)\hbar^2}{2mr^2} u - \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r} u = Eu.$$

Show that

$$u(r) = Ar^{\ell+1}e^{-br}$$

is a ground state solution to the Schrodinger equation above by finding the value of b in terms of a_0 , Z , and ℓ ($a_0 = 4\pi\epsilon_0\hbar^2/me^2$ = Bohr radius). Find the total energy, E , for this ground state. How does it differ from the typical Bohr energy below?

$$E_n = -\frac{1}{(4\pi\epsilon_0)^2} \frac{mZ^2e^4}{2\hbar^2} \frac{1}{n^2} = -\frac{\hbar^2}{2ma_0^2} \frac{1}{n^2}$$