Fundamental constants:

\[ c = \text{speed of light} = 3 \times 10^8 \text{ m/s} \]
\[ g = \text{accel. of gravity on Earth} = 10 \text{ m/s}^2 \]
\[ G = \text{gravitational constant} = 6.7 \times 10^{-11} \text{ N-m}^2/\text{kg}^2 \]

Photon energy \( E = \frac{hc}{\lambda} = 1240 \text{ eV-nm}/\lambda \)
1. A

2. Experiments have shown that a dark-adapted eye can detect a 0.001 sec duration flash of green light at a power level of only $4 \times 10^{-14}$ Watts. A green photon has 2.5 eV of energy (1 eV = $1.6 \times 10^{-19}$ Joules). How many photons is this?

   a. 40,000
   b. 4,000
   c. 10,000
   d. 100
   e. 10

   **Pulse energy** = $(4 \times 10^{-14} \text{ J/s}) \times (0.001 \text{ sec}) = 4 \times 10^{-17} \text{ J} \\
   \text{Energy in eV} = (4 \times 10^{-17} \text{ J}) \times (1 \text{ eV} / 1.6 \times 10^{-19} \text{ J}) = 250 \text{ eV} \\
   \text{One green photon has 2.5 eV of energy, so this must be 100 photons.}**

3. A scientist is trying to eject electrons from a metal by shining a light on it. The electrons are bound inside the metal by an energy of 4.2 eV. Which wavelength will eject electrons?

   a. 640 nm
   b. 420 nm
   c. 350 nm
   d. any of these
   e. none of these

   **The incoming photon must have at least 4.2 eV of energy. So its wavelength must be shorter than \( \frac{hc}{4.2 \text{ eV}} = 1240 \text{ eV-nm}/4.2 \text{ eV} = 295 \text{ nm}. \) Any longer wavelength will not work. So none of these.**

4. A beta particle, gamma ray, and alpha particle all have the same momentum. Which has the longest wavelength?

   a. beta particle.
   b. gamma ray.
   c. alpha particle.
   d. all the same.
   e. depends on gamma ray energy.

5. Particular red (600 nm) and blue (300 nm) lasers both shoot out the same number of photons per second. How does the **power output** of the two lasers compare?

   a. Both the same.
   b. Blue has 1/4 the power as red.
   c. Blue has 1/2 the power as red.
   d. Blue has 2 times the power as red.
   e. Blue has 4 times the power as red

   **Both output the same number of photons per second, but each blue photon has twice the energy of the red photons. So the energy/second = power is twice as large for the blue laser.**
6. A quantum particle in a box is in the lowest energy (ground) state. If the size of the box is increased, the wavelength and energy of the particle change as

a. wavelength shorter, energy larger
b. wavelength longer, energy smaller
c. wavelength shorter, energy smaller
d. wavelength longer, energy larger
e. wavelength and energy unchanged

7. A typical x-ray photon used in a dentist’s office to produce an x-ray of your teeth has an energy of 10,000 eV. Its wavelength is about

- a. 0.1 nm
- b. 1 nm
- c. 10 nm
- d. 100 nm
- e. 1000 nm

The wavelength is given by \( \lambda = \frac{1240 \text{ eV} - nm}{10,000 \text{ eV}} = 0.124 \text{ nm} \)

8. A hydrogen atom has quantum states with energies \(-13.6\text{eV}/n\). Which of the following transitions emits the shortest wavelength photon?

- a. \(n=2\) to \(n=1\)
- b. \(n=3\) to \(n=2\)
- c. \(n=3\) to \(n=1\)
- d. \(n=4\) to \(n=3\)
- e. all emit the same wavelength photon

\(n=3\) to \(n=1\) is the biggest energy change, corresponding to the shortest wavelength photon.

9. A particular quantum system has quantum states with energies

\(E_{(n=1)}=1\text{ eV}, E_{(n=2)}=4\text{ eV}, E_{(n=3)}=9\text{, }E_{(n=4)}=16\text{ eV}, \ldots\) This is NOT a hydrogen atom.

Calculate the wavelength of a photon emitted as a result of the \(n=3\) to \(n=2\) transition.

- a. 140 nm
- b. 410 nm
- c. 250 nm
- d. 1240 nm
- e. 620 nm

\(n=3\) to \(n=2\) corresponds to an energy loss of \(9\text{ eV} - 4\text{ eV} = 5\text{ eV}\). The photon must carry away 5 eV of energy. The corresponding wavelength is \(\lambda = \frac{1240 \text{ eV} - nm}{5 \text{ eV}} = 248 \text{ nm}\)
10. The energy levels of a hydrogen atom are given by $E = -\frac{13.6}{n^2}$ eV.
Calculate the wavelength of a photon emitted as a result of the $n=4$ to $n=3$ transition.

\begin{itemize}
  \item[a.] 2700 nm
  \item[b.] 1875 nm
  \item[c.] 360 nm
  \item[d.] 820 nm
  \item[e.] 650 nm
\end{itemize}

An electron loses $(-13.6/4^2 \text{ eV})-(-13.6/3^2 \text{ eV})=0.661 \text{ eV}$ of energy as it makes this transition. The energy is carried away by a photon of wavelength $\lambda=hc/E=1240 \text{ eV-nm}/0.661 \text{ eV} = 1875 \text{ nm}$

11. An electron is confined to a box of length $L$. It is in an excited state. The momentum of the particle is uncertain because

\begin{itemize}
  \item[a.] the particle is not in the quantum ground state.
  \item[b.] the concept of momentum is not well-defined.
  \item[c.] the particle is moving in two different directions.
  \item[d.] the particle has an electrostatic charge.
  \item[e.] the particle could quantum-mechanically tunnel out of the box.
\end{itemize}

12. Here is the first excited state wavefunction for a particle in a box. Compare the probabilities ($P$) of finding the particle at the indicated locations.

\begin{itemize}
  \item[a.] $P(0.25 \text{ nm})=P(0.75 \text{ nm})$
  \item[b.] $P(0.25 \text{ nm})<P(0.75 \text{ nm})$
  \item[c.] $P(0.25 \text{ nm})>P(0.75 \text{ nm})$
  \item[d.] the probabilities are uncertain
  \item[e.] need to know mass of particle
\end{itemize}

13. The force binding together neutrons and protons in the nucleus is

\begin{itemize}
  \item[a.] the Coulomb force
  \item[b.] the gravitational force
  \item[c.] the strong force
  \item[d.] the weak force
  \item[e.] none of the above
14. Neutral hydrogen has one electron orbiting around its nucleus. Which of the following is NOT the nucleus of an isotope of hydrogen?

a. One proton.
b. One proton, one neutron
c. One proton, two neutrons
**d. Two protons, two neutrons**
e. All of them are isotopes of hydrogen

15. $^8$C is an extremely unstable isotope of carbon. It has 6 protons and 2 neutrons in its nucleus. It decays by emitting a positron (anti-particle of electron). After the decay, it becomes

a. $^7$C
b. $^7$C
**c. $^8$B**
d. $^7$N
e. $^7$B

If it emits a positron, it loses a positive charge, meaning that a proton has changed to a neutron. The resulting isotope then has 5 protons and 3 neutrons. The total number of nucleons (8) has not changed.

16. A fossil bone has a $^{14}$C : $^{12}$C ratio that is 1/4 of the $^{14}$C : $^{12}$C ratio in the bone of a living animal. What is the approximate age of the fossil? ($^{14}$C half-life is 5,730 years).

a. 11,460 years
b. 17,190 years
c. 22,920 years
d. 45,840 years
e. 91,680 years

After each half-life, half the material has decayed. So after two half-lives, only ¼ of the original materials remains. Two half-lives is $2 \times 5730$ yrs = 11460 yrs.

17. $^{241}$Am is used in smoke detectors to ionize gas atoms with alpha particles it emits from its nucleus. In the $^{241}$Am nucleus, there are 95 protons and 241 total nucleons. After the alpha emission, $^{241}$Am becomes

a. $^{239}$Np
b. $^{237}$Np
**c. $^{239}$Pa**
d. $^{237}$Pa
e. $^{237}$U

By emitting an alpha particle, the nucleus loses two protons and two neutrons. The atomic weight goes to 237, and it has 93 protons.
18. A particular radioactive nucleus has 60 neutrons and 50 protons in the nucleus. The particle it emits when it decays is likely to be

- a. a neutron
- b. a proton
- **c. an electron**
- d. an alpha particle
- e. a gamma particle

This nucleus has too many neutrons to be stable. It would like to change some neutrons into protons. It can do this by emitting an electron (negative charge), and creating a positive charge in the nucleus by changing a neutron into a proton.

19. The Pauli exclusion principle says that

- a. no two particles are exactly identical
- b. fermions are excluded from the quantum ground state
- c. electrons are fermions
- **d. no two fermions can be in the same quantum state**
- e. all bosons have spin

20. In a hypothetical nuclear fission event, the original nucleus (binding energy 6 MeV/nucleon) has 200 nucleons, and splits into two nuclei, each with 100 nucleons (binding energy 6.2 MeV/nucleon). The TOTAL energy released in the fission of ONE nucleus is

- **a. 40 MeV**
- b. 20 MeV
- c. 0.4 MeV
- d. 620 MeV
- e. 0.2 MeV

Here we have the same number of nucleons before and after the fission, but they are bound more tightly afterwards by 0.2 MeV/nucleon, or a total of (200 nucleons) x (0.2 MeV/nucleon) = 40 MeV. So 40 MeV of energy is released by the fission of one nucleus.

21. A pure semiconductor is an insulator, but becomes useful electrically when

- a. it is cooled to low temperature
- b. not too large a magnetic field is applied
- **c. some of its atoms are replaced with different atoms**
- d. quantum states are created in it
- e. it is patterned to very small (nanometer) sizes