Name: _____

Class: _____

Due Date: _____

# E.1 Structure of the Atom

**Understandings**

- The Geiger-Marsden-Rutherford experiment and the discovery of the nucleus.
- Nuclear notation ${}^{A}_{Z}X$ where $A$ is the nucleon number, $Z$ is the proton number, and $X$ is the chemical symbol.
- Emission and absorption spectra provide evidence for discrete atomic energy levels.
- Photons are emitted and absorbed during atomic transitions.
- The frequency of the photon released during an atomic transition depends of the difference in energy level as given by $E = hf$.
- Emission and absorption spectra provide information on the chemical composition.

**Equations**

$E = hf$

**Additional HL Understandings**

- The relationship between the radius and nucleon number for a nucleus as given by $R = R_0 A^{1/3}$ and implications for nuclear densities.
- Deviations from Rutherford scattering at high energies.
- The distance of closest approach in head-on scattering experiments.
- The discrete energy levels in the Bohr model for hydrogen as given by $E = -\frac{13.6}{n^2}$ eV.
- The existence of quantized energy and orbits arise from the quantization of angular momentum in the Bohr model for hydrogen as given by $mvr = \frac{nh}{2\pi}$.

**Additional HL Equations**

$R = R_0 A^{1/3}$

$E = -\frac{13.6}{n^2}$ eV

$mvr = \frac{nh}{2\pi}$

**The solutions can be found on the YouTube channel Go Physics Go:**

https://www.youtube.com/@gophysicsgo/playlists

**Use your favorite sources to answer the following questions**

1. Draw and describe the main points of the *Thomson model of the atom*:

2. Describe the Geiger-Marsden-Rutherford experiment. Draw an image if you have to.

3. True or false: Your brain is mostly empty space.

4. Describe and draw the *Rutherford model of the atom*:

5. Which year were the following particles discovered?

| | | |
|---|---|---|
| Electron | Photon | Atomic Nucleus |
| Neutrino | Proton | Neutron |

6. Define *nucleon number A.*

7. Define *atomic number Z.*

8. Define *nucleon.*

9. Define *nuclide.*

10. Define *discrete* and *continuous.*

11. Circle the correct answers in italic font: Free electrons have *continuous/discrete* energy. Bound electrons in an atom have *continuous/discrete* energy.

12. Define *ground state* and *excited state* of an electron in an atom. Draw a figure.

13. Define *transition.*

14. Which has more energy: an electron in an atom which is close to its nucleus or an electron in an atom which is farther from its nucleus? Draw a figure.

15. Define *absorption spectra*. What happens to an electron in an atom during *photon absorption*? Draw a figure.

16. Define *emission spectrum*. What happens to an electron in an atom during *photon emission*? Draw a figure.

17. We use the equation $E = hf$ for *electromagnetic waves*. Define and give the units of each variable.

## Additional HL Content

18. Give the meaning of the equation $R = R_0 A^{1/3}$ and define each variable.

19. What is the meaning of *nuclear density*? What is the value of the *nuclear density*?

20. Use Newton's second law of motion, the equation for total energy, the equation for angular momentum $\vec{L} = r \times \vec{p}$, and the assumption that the angular momentum of an electron orbiting a hydrogen atom is quantized: $mvr = n\left(\frac{h}{2\pi}\right)$ to derive the equation for the energy of an electron orbiting a hydrogen atom is $E_{\text{electron}} \approx -\frac{13.6}{n^2}$ eV.

21. What is the meaning of the equation $E = \frac{-13.6\ \text{eV}}{n^2}$?

22. Describe the *Bohr model of the atom*.

Name: _____

Class: _____

Due Date: _____

# E.2 Quantum Physics

**Additional HL Understandings**

- The photoelectric effect as evidence of the particle nature of light.
- Photons of a certain frequency, known as the threshold frequency, are required to release photoelectrons from the metal.
- Einstein's explanation using the work function and the maximum kinetic energy of the photoelectrons as given by $E_{\max} = hf - \Phi$ where $\Phi$ is the work function of the metal.
- Diffraction of particles as evidence of the wave nature of matter.
- Matter exhibits wave-particle duality.
- The de Broglie wavelength for particles as given by $\lambda = \frac{h}{p}$.
- Compton scattering of light by electrons as additional evidence of the particle nature of light.
- Photons scatter off electrons with increased wavelength.
- The shift in photon wavelength after scattering off an electron as given by $\lambda_{\mathrm{f}} - \lambda_{\mathrm{i}} = \Delta\lambda = \frac{h}{m_{\mathrm{e}}c}(1 - \cos\theta)$.

**Additional HL Equations**

$$E_{\max} = hf - \Phi$$

$$\lambda = \frac{h}{p}$$

$$\lambda_{\mathrm{f}} - \lambda_{\mathrm{i}} = \Delta\lambda = \frac{h}{m_{\mathrm{e}}c}(1 - \cos\theta)$$

If you are interested in learning more about atomic, quantum, and nuclear physics then please read the book *The Quantum Story: A History in 40 Moments* by Jim Baggott.

Also watch all the videos in this website:
https://www.learner.org/series/physics-for-the-21st-century/

**The solutions can be found on the YouTube channel Go Physics Go:**

https://www.youtube.com/@gophysicsgo/playlists

**Use your favorite sources to answer the following questions**

1. Briefly describe the *photoelectric effect*.

2. About how long does it take for the electrons to leave the metal during the photoelectric effect?

3. Define *critical/threshold frequency*.

4. What will happen to the metal if the intensity of the electromagnetic wave is increased while it is still below the *critical/threshold frequency*? Will the photoelectric effect occur?

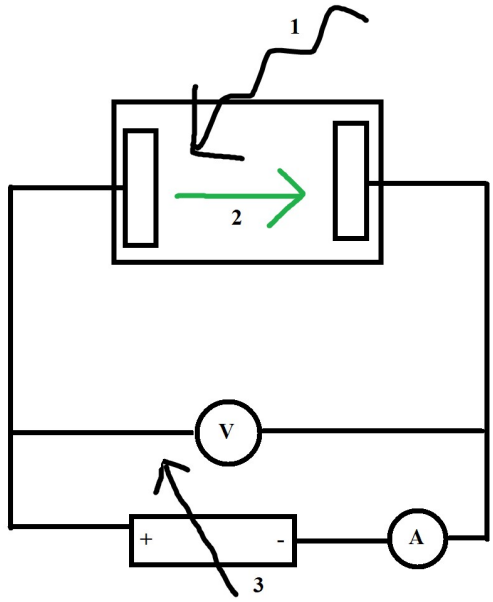
5. What will happen to the electrons if the intensity of the electromagnetic wave is increased while it is above the *critical/threshold frequency*?

6. What is the *work function* $\varphi$?

7. Describe the equation given in the IB physics data booklet: $E_{\max} = hf - \varphi$.

8. Draw an $E_{\max}$ vs. incoming frequency graph for three metals. What does the horizontal and vertical intercepts tell us? What does the slope tell us?

9. Describe, step by step, what is happening in the lab setup below.




Step 1:

Step 2:

Step 3:

10. Define *stopping potential/voltage*.

11. From the lab setup from question 9 draw a graph of the *current vs. potential difference across the anode and cathode* with the same incoming frequencies and different intensities.

12. From the lab setup from question 9 draw a graph of the *current vs. potential difference across the anode and cathode* with different incoming frequencies.

13. What is the meaning of *energy is quantized*?

14. State ***two*** experiments in which light behaves as a wave. Do not explain the experiments, just state them.

15. State ***two*** experiments in which light behaves as a particle. Do not explain the experiments, just state them.

16. What is the *de Broglie hypothesis*? What is the equation?

17. Usain Bolt has a mass of 94 kg. He is running with a speed of 9.58 m/s. What is his wavelength?

18. An electron, which has a mass of $9.11 \times 10^{-31}$ kg, is traveling with a speed of 9.58 m/s. What is its wavelength?

19. Where can we see particles, such as electrons, diffract? In which experiment do electrons diffract?

20. What is the meaning of *wave-particle duality*?

21. Describe the *Compton effect*.

Name: _____

Class: _____

Due Date: _____

# E.3 Radioactive Decay

**Understandings**

- Isotopes.
- Nuclear binding energy and mass defect.
- The variation of the binding energy per nucleon with nucleon number.
- The mass-energy equivalence as given by $E = mc^2$ in nuclear reactions.
- The existence of the strong nuclear force, a short-range, attractive force between nucleons.
- The random and spontaneous nature of radioactive decay.
- The changes in the state of the nucleus following alpha, beta, and gamma radioactive decay.
- The radioactive decay equations involving $\alpha$, $\beta^-$, $\beta^+$, and $\gamma$.
- The existence of neutrinos $\nu$ and antineutrinos $\bar{\nu}$.
- The penetration and ionizing ability of alpha particles, beta particles, and gamma rays.
- The activity, count rate, and half-life in radioactive decay.
- The changes in activity and count rate during radioactive decay using integral values of half-life.
- The effect of background radiation of count rate.

**Equations**

$E = mc^2$

$\lambda = \frac{hc}{E}$

**Additional HL Understandings**

- The evidence for the strong nuclear force.
- The role of the ratio of neutrons to protons for the stability of nuclides.
- The approximate constancy of binding energy curve above a nucleon number of 60.
- The spectrum of alpha and gamma radiations provides evidence for discrete nuclear energy levels.
- The continuous spectrum of beta decay as evidence for the neutrino.
- The decay constant λ and the radioactive decay law as given by $N = N_0 e^{-\lambda}$ .
- The decay constant approximates the probability of decay in unit time only in the limit of sufficiently small $\lambda t$.
- The activity as the rate of decay as given by $A = \lambda N = \lambda N_0 e^{-\lambda t}$.
- The relationship between half-life and the decay constant as given by $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$.

**Additional HL Equations**

$N = N_0 e^{-\lambda t}$

$A = \lambda N = \lambda N_0 e^{-\lambda}$

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

**The Evil Revealed in First US Nuclear Test: 74 Years Ago Over Bikini**
https://www.activistpost.com/2020/06/the-evil-revealed-in-first-us-nuclear-test-74-years-ago-over-bikini.html

**MIT Scientists: Nuclear Fusion Energy Could Be Closer Than Thought**
https://oilprice.com/Alternative-Energy/Nuclear-Power/MIT-Scientists-Nuclear-Fusion-Energy-Could-Be-Closer-Than-Thought.html

**The solutions can be found on the YouTube channel Go Physics Go:**

https://www.youtube.com/@gophysicsgo/playlists

**Use your favorite sources to answer the following questions**

1. Define *isotope.*

2. *Isotopes* have the same _____ properties but different _____ properties.

3. Define *mass defect*. Units?

4. Which has more mass: two individual protons or two protons in the same nucleus?

5. Define *binding energy*. Units?

6. **Use a pencil and ruler!** Draw and label the *binding energy curve*. Label the horizontal and vertical axis. Label the most stable element.

7. Define *atomic mass unit*. Units?

8. Use the equation $\Delta E = \Delta m \times c^2$ to find the energy equivalent of 1 u in Joules and $\frac{\text{MeV}}{\text{c}^2}$.

9. Determine the binding energy per nucleon for a neutral carbon atom.

10. Define *transmutation.*

11. What happens in nuclear decay if the *mass difference* is positive? Is nuclear decay possible?

12. What happens in nuclear decay if the *mass difference* is negative? Is nuclear decay possible?

13. Describe the *strong nuclear force*.

14. Define *random* and *spontaneous.*

15. *Radioactive decay* is both _____ and _____.

16. Define *alpha particle*. What is it made of? Charge?

17. What is the difference between an *alpha particle* and a *helium atom*?

18. Give two examples of *alpha decay*:

19. Define *neutrino*. What is it made of? Charge? Mass?

20. Define *anti-neutrino*. What is it made of? Charge? Mass?

21. Define *positron*. What is it made of? Charge? Mass?

22. Define *beta plus particle*. What is it made of? Charge? Mass?

23. What happens to a proton in a decaying nucleus during *beta plus decay*?

24. Give two examples of *beta plus decay*:

25. Define *beta minus particle*. What is it made of? Charge? Mass?

26. What is the difference between a *beta minus particle* and an *electron*?

27. What happens to a neutron in a decaying nucleus during *beta minus decay*?

28. Give two examples of *beta minus decay*:

29. Why was the neutrino postulated?

30. What is the charge and mass of an electron? What is the charge and mass of a neutrino ν?

31. Define *gamma ray*. What is it made of? Charge? Mass?

32. Why is it not correct to use the term *gamma particle*?

33. What is happening to an atom during *gamma decay*?

34. Give two examples of *gamma decay*: Gamma decay takes an excited and unstable atom and then makes it stable by releasing energy (as an electromagnetic wave) from the nucleus.

35. Define *ionization.*

36. Which particles have the most *ionizing ability* out of alpha particles, beta particles, and gamma rays?

37. Define *to penetrate.*

38. Define *penetrating power*. Which object can we use to stop an *alpha particle*? A *beta particle*? A *gamma ray*?

39. Define *activity*. Units? Use a **pencil and ruler!** Draw an activity vs. time graph for a radioactive/unstable element.

40. Define *count rate*. Units?

41. Define *half-life*. Units?

42. Define *background radiation.*

## Additional HL Content

43. Why do stable nuclei have more neutrons than protons?

44. What is the ratio of neutrons to protons for stable nuclei?

45. Circle the correct answer: Alpha particles leave the nucleus with *continuous/discrete* energy levels.

46. Circle the correct answer: Beta minus particles leave the nucleus with *continuous/discrete* energy levels.

47. Circle the correct answer: Beta plus particles leave the nucleus with *continuous/discrete* energy levels.

48. Circle the correct answer: Gamma rays leave the nucleus with *continuous/discrete* energy levels.

49. What is the meaning and units of the *decay constant* $\lambda$?

50. Describe and define the variables in the radioactive decay law equation $N(t) = N_0 e^{-\lambda}$ .

51. What is the meaning and units for *activity A*? Describe and define the variables in the equation $A(t) = \lambda N(t) = \lambda N_0 e^{-\lambda t}$.

52. State the relationship between the half-life and the decay constant.

Name: _____

Class: _____

Due Date: _____

# E.4 Fission

**Understandings**

- Energy is released in spontaneous and neutron-induced fission.
- The role of chain reactions in nuclear fission reactions.
- The role of control rods, moderators, heat exchangers, and shielding in a nuclear power plant.
- The properties of the products of nuclear fission and their management.

**The solutions can be found on the YouTube channel Go Physics Go:**

https://www.youtube.com/@gophysicsgo/playlists

1. Define *nuclear fission.*

2. Give two examples of *nuclear fission*:

3. Define *chain reaction.*

4. Define *critical mass*. Units?

5. Define *induced process.*

6. What are the uses of the following objects in a nuclear reactor?
   a. *control rod*

   b. *moderator*

   c. *heat exchanger*

   d. *fuel rod*

7. State two benefits and two drawbacks to using *nuclear power.*

Name: _____

Class: _____

Due Date: _____

# E.5 Fusion and Stars

**Understandings**

- The stability of stars relies on an equilibrium between outward radiation pressure and inward gravitational forces.
- Fusion is a source of energy in stars.
- The conditions leading to fusion in stars in terms of density and temperature.
- The effect of stellar mass on the evolution of a star.
- The main regions of the Hertzsprung-Russell (HR) diagram and how to describe the main properties of stars in these regions.
- The use of stellar parallax as a method to determine the distance *d* to celestial bodies as given by $d(\text{parsec}) = \frac{1}{p(\text{arc}-\text{second})}$
- How to determine stellar radii

**Equations**

$$d(\text{parsec}) = \frac{1}{p(\text{arc}-\text{second})}$$

**The solutions can be found on the YouTube channel Go Physics Go:**

https://www.youtube.com/@gophysicsgo/playlists

**Use your favorite sources to answer the following questions**

6. Define *nuclear fusion.*

7. Give two examples of *nuclear fusion*:

8. Define *celestial.*

9. Define *star*.

10. Define *thermal gas pressure*.

11. Define *radiation pressure.*

12. Define *gravitational pressure*.

13. Define *stellar equilibrium*.

14. Define *main sequence star*.

15. Define *Sun*.

16. Describe the *proton-proton cycle*.

17. Define *apparent brightness b.* Units?

18. Define *luminosity L.* Units?

19. Define a *perfect black body*.

20. Describe *Wien's displacement law*.

21. Describe the *absorption spectrum*.

22. Describe *main sequence stars*.

23. Describe the *Hertzsprung-Russell diagram*.

24. Describe the *instability strip*.

25. Define a *red giant*.

26. Define a *red supergiant*.

27. Define a *dwarf star*.

28. Define *electron degeneracy pressure*.

29. Define a *white dwarf*.

30. Describe what happens after a *supernova*.

31. Describe the term *evolutionary path*.

32. Describe the equation $L \propto M^{3.5}$.

33. Define *astronomical unit*.

34. Define *light year*.

35. Define *stellar parallax* (or *parallax method*).

36. Define *parallax angle*.

37. Define *arc second*.

38. Define *parsec*.

39. Describe the equation $d(\text{parsec}) = \frac{1}{p(\text{arc}-\text{secon }\text{)}}$.