Study Sheet for Modern Physics

Classical mechanics was meant to provide the general rules that govern the dynamics of all material bodies, such as cannon balls, planets, and pendulums, and is defined as the study of such things as electricity, energy, heat, light, sound, motion, color, mechanical energy, solar energy, states of matter.

Modern Physics is defined as dealing with ideas such as objects moving at the speed of light, the inside of atoms, extreme temperatures, and when the objects are super huge.

Dalton's model was that the atoms were tiny, indivisible, indestructible particles and that each one had a certain mass, size, and chemical behavior that was determined by what kind of element they were.

Three new theories were needed to solve the problems related to things that are beyond what we can see and experience and prove with laws:

1. Special relativity solved the problem of objects moving at very high velocities.
2. General relativity solved the problem of large scale (strong gravity)
3. Quantum mechanics solved the problem of super small scale such as atoms, electrons and sub-atomic particles.

An atom is made up of three subatomic particles -- protons, neutrons and electrons. The center of an atom, called the nucleus, is composed of protons and neutrons. Protons are positively charged, neutrons have no charge at all and electrons are negatively charged. The proton-to-electron ratio is always one to one, so the atom as a whole has a neutral charge. For example, a carbon atom has six protons and six electrons.

At the present 118 elements have been identified.

In 1897, J. J. Thomson discovered the existence of the electron, marking the beginning of modern atomic physics.

Most of the mass of an atom is in the nucleus. Most of the volume of an atom is where the electrons are.

Hydrogen is small compared to other atoms. To scale it up: if the proton in its nucleus was enlarged to the size of a basketball, the electron would be some 20 miles away.

The number of protons in the nucleus is represented by "Z", the atomic number. The atomic mass of the element (number of protons plus the number of neutrons) is represented by "A".

An atom of carbon-14 contains 6 protons and 8 neutrons and is denoted $^{14}\text{C}$.

The unit of length for measuring atomic sizes is the angstrom (Å), which is defined as $1 \times 10^{-10}$ meters. The diameter of an atom is approximately 2 to 3 Å.

The mass (weight) of an atom is measured with the atomic mass unit (amu) which is exactly $\frac{1}{12}$ of the mass of a C-12 atom.
Isotopes are atoms of the same element with different numbers of neutrons and therefore different masses.

Subatomic particles are divided into two classes, consisting of Leptons and Quarks. The Lepton classification of subatomic particles consists of 6 fundamental particles: Electron, Muon, Tau, Electron Neutrino, Muon Neutrino, Tau Neutrino

The fundamental particles among the Quarks are:
Up and Down, Charm, Strange, Top and Bottom Quarks

Marie and Pierre Curie’s work in radioactivity revolutionized science in the late 19th Century. Marie Curie discovered the radioactive substances radium and polonium. Marie Curie’s hypothesis that radiation was “an atomic property” transformed forever how man would view the atom. Their understanding of the atom has led to many uses of it including medical and energy.

Radioactivity is the spontaneous disintegration of atomic nuclei. Radioactivity is the result of an atom trying to reach a more stable nuclear configuration. The process of radioactive decay can be achieved via three primary methods; (1.) a nucleus can change one of its neutrons into a proton with the simultaneous emission of an electron (beta decay), (2.) by emitting a helium nucleus (alpha decay), or (3.) by spontaneous fission (splitting) into two fragments. Often associated with these events is the release of high energy photons or gamma rays. There is a fourth type of radiation called X-rays.

Each individual radioactive substance has a characteristic decay period or half-life. A half-life is the interval of time required for one-half of the mass of an atom of a radioactive sample to decay. The radioactive half-life for a given radioisotope is the time for half the radioactive nuclei in any sample to undergo radioactive decay. After one half-life there will be one half of the original sample left. After two half-lives, there will be one fourth the original sample, after three half-lives one eight the original sample, and so forth.

Henri Becquerel and others observed three clearly different types of radiation, but no one knew exactly what any of them were, so they were simply named alpha (α), beta (β) and gamma (γ) for the first three letters of the Greek alphabet. It was only later that the radiation was shown to consist of familiar things: helium nuclei, electrons, and high-energy electromagnetic waves.

Radioactive decay is the process by which an unstable atomic nucleus loses energy by emitting ionizing particles or radiation.

The chemical reactions involve the transfer, loss, gain and sharing of electrons and nothing takes place in the nucleus. Nuclear reactions involve the decomposition of the nucleus and have nothing to do with the electrons.

There are four forces in nature:

<table>
<thead>
<tr>
<th>Force</th>
<th>Particle</th>
<th>Mass</th>
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Gravitational Force is the weakest but also the most quantity. The Strong Nuclear Force is the strongest and holds the atom together so prevents everything from falling apart.

Nuclear Fission is the breakup of a large nucleus into two smaller nuclear fragments. Accompanying the break-up of the large nucleus is the release of energy determined by the mass defect. When a nucleus fissions, it splits into several smaller fragments. These fragments, or fission products, are about equal to half the original mass. Two or three neutrons are also emitted.

Fusion is the process of combining the nuclei of smaller atoms (less protons & neutrons and hence, a smaller atomic number) to create a larger atom.

This is an example of nuclear fission

\[ {^{235}}U + n \rightarrow {^{239}}U^* \rightarrow {^{85}}Xe + {^{97}}Sr + 2n \]

This is an example of nuclear fusion

\[ \frac{1}{2}H + \frac{3}{2}H \rightarrow \frac{3}{2}He + \frac{1}{2}H + 17.6 \text{MeV} \]

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).

At the point where the chain reaction can become self-sustaining, this is referred to as critical mass.

Uses for radiation: Medical testing, Sterilize food, Manufacturing products, Smoke detectors

Theory of Relativity

Einstein’s theory of special relativity created a fundamental link between space and time. The universe can be viewed as having three space dimensions — up/down, left/right, forward/backward — and one time dimension. This 4-dimensional space is referred to as the space-time continuum.

Postulate 1: All the laws of physics are the same in all inertial frames of reference. All uniform motion is relative.

The second postulate is: The speed of light (in a vacuum) is the same in all inertial frames of reference.

In the special theory of relativity Einstein demonstrated that neither mass nor energy were conserved separately, but that they could be traded one for the other and only the total "mass-energy" was conserved. The relationship between the mass and the energy is contained in what is probably the most famous equation in science, \( E = mc^2 \)
Predictions of Special Relativity

- **As velocity increases:**
  - Lengths shrink (contract)  **Length contraction**
  - Masses increase  **Mass increase**
  - Clocks slow down  **Time dilation**

The speed of light is a constant and moves at $3.0 \times 10^8$ m/s.

This is a basic postulate of the Theory of General Relativity. It states that a uniform gravitational field like that near the earth is equivalent to a uniform acceleration.

Einstein discovered that there is a relationship between mass, gravity and space-time. Mass distorts space-time, causing it to curve.

There are five main ideas represented in Quantum Theory
1. Energy is not continuous, but comes in small but discrete units.
2. The elementary particles behave both like particles *and* like waves.
3. The movement of these particles is inherently random.
4. It is physically impossible to know both the position and the momentum of a particle at the same time. The more precisely one is known, the less precise the measurement of the other is.
5. The atomic world is nothing like the world we live in.

In quantum mechanics, the Heisenberg uncertainty principle states by precise inequalities that certain pairs of physical properties, such as position and momentum, cannot be simultaneously known to arbitrarily high precision.

Scientists interpret quantum mechanics to mean that a tiny piece of material like a photon or electron is both a particle and a wave. It can be either, depending on how one looks at it or what kind of an experiment one is doing.
1. Briefly describe the difference between Classical Physics and Nuclear Physics.

2. Name 3 things (areas of study) that we studied in Classical Physics.

3. An atom is made up of 3 main subatomic particles – they are:
   1. ______________________________
   2. ______________________________
   3. ______________________________

4. Of these 3 particles, what charge do they have?
   Negative = ______________________________
   Positive = ______________________________
   Neutral = ______________________________

5. Most of the mass of an atom is in the ______________________________.

6. Most of the volume of an atom is where the ______________________________ are.

7. The units of measurement for an atom include:
   Mass which is measured in: ______________________________
   Length which is measured in: ______________________________

8. Name the 2 classes of subatomic particles (hint: not the ones in the above questions):
   1. ______________________________
   2. ______________________________


10. What are the 3 different types of radiation?
    1. ______________________________
    2. ______________________________
    3. ______________________________
11. Name the 4 fundamental forces of nature:
   1. ___________________________
   2. ___________________________
   3. ___________________________
   4. ___________________________

12. Name 2 uses for radiation:
   1. ___________________________
   2. ___________________________

Match the following terms with the definition:

1. Fusion __________
   a. Critical mass is referred to the point where this becomes self-sustaining.

2. Gluon __________
   b. Atoms of the same element with different numbers of neutrons and therefore different masses.

3. Chain Reaction __________
   c. The process of combining the nuclei of smaller atoms to create a larger atom.

4. Space-time continuum __________
   d. A repetitive process involving fission.

5. \[ E = mc^2 \] __________
   e. The most common isotope

6. Uranium 238 __________
   f. The breakup of a large nucleus into two smaller nuclear fragments.

7. Fission __________
   g. The particle of strong nuclear force.

8. Isotope __________
   h. A subatomic particle consisting of 6 different types with some ‘strange’ names.

9. Quark __________

10. Nucleus __________
    i. Einstein’s famous formula
13. Isotope A decays to Isotope B and has a half-life of six months. If you begin with 500 grams of isotope A, how much of each isotope will be present

A after 6 months ________________   B after 6 months ________________
A after 12 months ________________    B after 12 months ________________
A after 18 months ________________   B after 18 months ________________

14. The half-life of carbon-14 is 5,730 years, and carbon-14 decays to nitrogen-14. If an Egyptian mummy contained 10 grams of carbon-14 when it was buried and now has 5 grams how old is the mummy? ________________ years.

15. How many grams of nitrogen-14 were produced during that time? ________________

16. In another 5,730 years, how much carbon-14 will remain? ________________

17. Answer the following questions based on the two formulas below:

Formula 1 \[ ^{238}U + n \rightarrow ^{239}U \rightarrow ^{239}Xe + ^{90}Sr + 2n \]

Formula 2 \[ ^{1}H + ^{1}H \rightarrow ^{4}He + ^{1}n + 17.6 \text{MeV} \]

Which formula is an example of Fusion? ________________

Which formula is an example of Fission? ________________

Name an Isotope in one of the formulas. ________________

Name an element in one of the formulas. ________________

What is the major item that is produced in both of the formulas? ________________

Which formula would be the most profitable in producing usable resources? ________________

18. In 1897 J.J. Thomson discovered the ________________ marking the beginning of modern atomic physics.

19. As of today, how many elements have been identified? ________________

20. If the proton in the nucleus of a Hydrogen atom is enlarged to the size of a baseball the electron would be ________________ miles away.

21. The atomic mass of an atom is represented by the letter A and is the sum of the number of ________________ and ________________.
22. Carbon – 14 or $^{14}$C is an ______________ of the carbon atom.

23. Each individual radioactive substance has a characteristic decay period which is called ________________.

24. What is needed to maintain a chain reaction? ________________ ________________.

25. Einstein’s second postulate is: ________________________________.

26. What is Einstein’s most famous equation? ________________.

27. List the three predictions of Special Relativity.
   A. ____________________________________________
   B. ____________________________________________
   C. ____________________________________________

28. When a giant star collapses, its remaining mass becomes so concentrated that it shrinks to an indefinitely small size. This is called a ____________________ ________________.

29. According to Einstein’s General Relativity ________________ is the result of massive objects bending the space-time geometry.

30. ________________ ________________ evolved as a new branch of theoretical physics during the first few decades of the 20th century in an effort to understand the basic properties of matter.

31. Two of the five main ideas of Quantum Theory are: 1. Elementary particles behave both like ________________ and like ________________ 2. Energy is not continuous, but comes in small but ________________ ________________.

32. The speed of light is a constant and moves at a rate of ________________ m/s.

33. In quantum mechanics, the ________________ ________________ states by precise inequalities that certain pairs of physical properties, such as position and momentum, cannot be simultaneously known with high precision.

34. Using the Periodic Table of Elements, answer the following questions.
   What is the symbol for Osmium? __________
   What is the atomic Number for Lead? __________
   Is Bismuth (Bi) radioactive? Yes or No __________
   What is the atomic weight of Copper (Cu)? __________
   Is Xenon (Xe) a liquid at room temperature? Yes or No __________
1. Briefly describe the difference between Classical Physics and Nuclear Physics.

2. Name 3 things (areas of study) that we studied in Classical Physics.
   electricity, energy, heat, light, sound, motion, color, mechanical energy, solar energy, states of matter

3. An atom is made up of 3 main subatomic particles – they are:
   1. __Proton___________________
   2. __Neutron___________________
   3. __Electron___________________

4. Of these 3 particles, what charge do they have:
   Negative = _____ Electron___________________
   Positive = _____ Proton___________________
   Neutral = _____ Neutron___________________

5. Most of the mass of an atom is in the __Nucleus_________________.

6. Most of the volume of an atom is where the __electrons________ are.

7. The units of measurement for an atom include:
   Mass which is measured in: __atomic mass unit (amu )________
   Length which is measured in: __angstrom (Å)________________

8. Name the 2 classes of subatomic particles (hint: not the ones in the above questions):
   1. __Lepton___________________
   2. __Quarks___________________

9. The work of __Marie ( Madame)__________ and Pierre __Curie_____________ and
   Henri __Becquerel__________ in radioactivity revolutionized science in the late 19th Century.

10. What are the 3 different types of radiation:
    1. ____ Alpha particles __________________________
2. **Beta particles**

3. **Gamma rays & Xrays**

11. Name the 4 forces of nature:

   1. **Weak**
   2. **Strong**
   3. **Gravitational**
   4. **Electromagnetic**

12. Name 2 uses for radiation:

   1. **Medical testing, Sterilize food, Manufacturing products, Smoke detectors**
   2. _________________________________

Match the following terms with the definition:

1. **Fusion** ______c_______
   a. Critical mass is referred to the point where this becomes self-sustaining.

2. **Gluon** ______g_________
   b. Atoms of the same element with different numbers of neutrons and therefore different masses.

3. **Chain Reaction** ______a_______
   c. The process of combining the nuclei of smaller atoms to create a larger atom

4. **Space-time continuum** ______k_______
   d. The center of an atom

5. **E = mc^2** ______m_______
   e. The most common isotope

6. **Uranium 238** ______e_______
   f. The breakup of a large nucleus into two smaller nuclear fragments.

7. **Fission** ______f_______
   g. The particle of strong nuclear force.

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Formula 2: 
\[ ^{1}H + ^{1}H \rightarrow ^{4}He + ^{1}H + 1.6 MeV \]

Which formula is an example of Fusion? _______ A _______
Which formula is an example of Fission? _______ B _______
Name an Isotope in one of the formulas. _______________
Name a chemical in one of the formulas. _______ Hydrogen _______
What is the major item that is produced in both of the formulas? _____ Energy _______
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   C. ________________________________

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