Problem 1
The Correspondence Principle.
(a) State the Correspondence Principle.

According to the correspondence principle, when energy levels are closely spaced, quantisation should have little effect. Using Bohr’s theory of the atom, closely spaced energy levels occur when the quantum number, \( n \), is large.

We will investigate the correspondence principle in relation to the frequency of a photon of light emitted by an atomic transition. Consider the photon emitted as a result of a transition of the electron from the \( n_i = n \) to the \( n_f = n - 1 \) energy level.

(b) Using the results of Bohr’s theory for an atom of nuclear charge \( Z \), show that the frequency of the emitted photon is given by

\[
f_{qu} = \frac{Z^2 mk^2 e^4}{4\pi \hbar^3} \frac{2n - 1}{n^2(n - 1)^2}.
\]

(c) Show that this reduces to

\[
f_{qu} \approx \frac{Z^2 mk^2 e^4}{2\pi \hbar^3 n^3}
\]

for large \( n \).

(d) Classically, electromagnetic theory predicts that an electron ‘orbiting’ the nucleus will emit radiation at the same frequency as the frequency of motion of the moving charge, i.e. the electron.

Show that the classical frequency of revolution of the electron in the \( E_n \) energy level is given by

\[
f_{cl} = \frac{mk^2 Z^2 e^4}{2\pi \hbar^3 n^3}
\]

which is identical to the frequency using Bohr’s quantum approach.

Problem 2
Tipler & Llewellyn: Modern Physics Chapter 4, problem 43.

Problem 3
Tipler & Llewellyn: Modern Physics Chapter 4, problem 50.
Problem 4
An astrophysicist proposes that a nearby galaxy is made of anti-matter. The scientist suggests that this galaxy, much like our own, consists mostly of hydrogen, except that this other galaxy is made up of “anti-hydrogen.” Anti-hydrogen is made up of a nucleus consisting of an anti-proton and is surrounded by a positron (anti-electron). An anti-proton is identical to a proton in every respect, except that it is negatively charged, and a positron is identical to an electron, except it is positively charged.

The astrophysicist has applied for funding to observe the spectral lines of this galaxy; the idea being that the spectral lines of anti-hydrogen will be unique and thus, confirm the existence of this anti-matter galaxy. The proposal requests three years of funding for the principal investigator, a post-doctoral fellow, and a graduate student to perform this investigation. The program officer sends it onto you for review. Write a brief, 1-2 paragraph review describing the scientific merit of this work and whether you support funding this endeavour.

Problem 5
Suppose that Coulomb’s law of electric attraction was a square-law, and not an inverse-square law.

Consider the force, \( \vec{F} = -br^2 \hat{r} \), where the negative sign indicates an attractive force. A particle of mass \( m \) is moving in a circle under the influence of this force.

(a) Use Bohr’s approach to show that only certain ‘orbits’ are allowed and that they occur when \( r_n \propto n^2 \).

(b) Using your results, determine the speed of the particle, \( v_n \).

(c) Recall the relationship between force (F) and potential energy (U) and show that, in this case, \( U \propto r^3 \).

(d) Show that the total energy of the system is given by \( E_n \propto n^5 \).

(e) Repeat this analysis for the case of an attractive force that is inversely proportional to distance, \( \vec{F} = -\frac{b}{r} \hat{r} \). Describe any difficulties that arise from a force of this nature.

Problem 6
A hypothetical atom has only two excited states, at 4.0 and 7.0 eV, and has a ground state ionisation energy of 9.0 eV. If we used a vapour of such atoms for the Franck-Hertz experiment, determine the voltages at which we would expect to see decreases in the current. List all voltages up to 20 V, and make a sketch of the current as a function of voltage.

Problem 7
Identify and memorise the first twenty (20) elements of the periodic table.