Question 1 A 1 kg piece of gold was heated from 300 K to 650 K. Estimate the change of mass of this sample due to relativistic effects. Heat capacity of gold is 128 J·K⁻¹·kg⁻¹ at 300 K and 135 J·K⁻¹·kg⁻¹ at 650 K; for the other temperatures, assume that it is changing linearly.
(15 points)

Question 2 Answer the following short questions:

A) How many electrons can be put into h-type orbitals?
B) Draw the shape of the 3dₓ² orbital.
C) How many quarks constitute a proton?
D) What is tachyon?
E) Which energy is larger: X-ray photon or infrared photon?
F) How many minima has 3rd excited (n=3) wave function of 1-dimensional harmonic oscillator?
G) List 4 different quark flavors.
H) List 3 different leptons.
I) What is the relativistic counterpart of Schrödinger equation?
J) What is the name of quantum statistics for protons?
K) What is the change in proton number Z and neutron number N during a radioactive alpha decay of a nucleus?
L) What is the name of the antiparticle of electron?
(12 points)

Question 3 There are 4 general types of fundamental interactions (gravitational, electromagnetic, weak, and strong) in the universe. However, for different pairs of particles, the actual force is not always originating from all of these types. List all types of interaction between:

A) Two protons
B) Two neutrons
C) Two neutrinos
D) Two electrons
E) Proton and neutron
F) Proton and electron
(6 points)
Question 4 List at least one famous discovery done by the persons listed below. The explanation should not use the name of the scientists, e.g.

(James Maxwell → Maxwell equations) would be wrong but

(James Maxwell → equations of electrodynamics) or (James Maxwell → $\nabla \cdot \mathbf{E} = 4\pi \rho$) would be right.

A) Hideki Yukawa →
B) Richard Feynman →
C) Albert Einstein →
D) Hendrik Lorentz →
E) Pieter Zeeman →
F) Max Planck →
G) Niels Bohr →
H) Werner Heisenberg →
I) Wolfgang Pauli →
J) Satyendranath Bose →

(10 points)

Question 5 A particle of mass $m$ moves in a potential $V(r) = -V_o$ when $r < a$, and $V(r) = 0$ when $r > a$. Find the least value of $V_o$ such that there is a bound state of zero energy and zero angular momentum.

(15 points)

Question 6 Consider the one-dimensional Schrödinger equation with

$$V(x) = \begin{cases} \frac{m}{2} \omega^2 x^2 & x > 0 \\ +\infty & x < 0 \end{cases}$$

Find the energy eigenvalues.

(15 points)

Question 7 Consider an electron in a uniform magnetic field in the positive $z$-direction. The result of a measurement has shown that the electron spin is along the position $x$-direction at $t = 0$. For $t > 0$ compute quantum mechanically the probability for finding the electron in the state (a) $S_x = 1/2$, (b) $S_x = -1/2$, and (c) $S_z = 1/2$.

(15 points)
Question 8  Use the Bohr-Sommerfeld quantization rule to calculate the allowed energy levels of a ball which is bouncing elastically in a vertical direction.

(12 points)