1. **Energy-loss in matter, muons, underground experiments**
   The range of particle in matter is defined as

   $$R = \int_E^0 \frac{dE}{dE/dx}.$$

   a) Work out the range of a muon under the assumption of approximative energy loss formula (i.e. a and b energy independent):

   $$-\frac{dE}{dx} = a + b \cdot E$$

   Assume $a = 1.8$ MeV cm^2 g^{-1} and $b = 4.4 \times 10^{-6}$ cm^2 g^{-1}.
   b) Draw the range of muon in rock as a function of muon initial energy from 1 GeV to 5 TeV. You may use computer or work with pen and paper. Use a typical rock density of $\rho = 2.7$ g/cm^3.
   Place the experiments EMMA, Homestake and MACRO at their relevant depths at y-axis and read their muon energy cutoff from the x-axis. Use the depths as stated in lecture slides 5.9, 4.2 and 4.3. [note: X mwe = X metres of water equivalent, depth in metres of rock is $X * \rho_{water}/\rho_{rock}$]

2. **Cosmic-ray propagation, the Milky Way**
   From a galactic source to the observer at Earth the charged cosmic-rays propagation is affected by the galactic magnetic fields.
   a) Taken that most HE cosmic-rays are accelerated within our Milky Way (for example in SNRs) and that charged particles in magnetic fields exhibit gyromotion with gyroradius

   $$R = 3.3 \times 10^{12} E/(ZB),$$

   where R is the gyroradius in centimetres, E is the energy in GeV, Z is the charge number of the CR nucleus and B is the magnetic flux density in μG.
   Also assume that $B = 3\mu$G inside the galactic disk, B is paraller to the galactic disk and that B decreases to zero within the galactic halo.
   Consider the propagation of HE cosmic-rays within the galaxy. Argue that the highest energy cosmic-rays observed at Earth cannot originate from galactic sources.
   Hint: Make small estimative calculations of gyroradius as a function of E and Z.
   b) Can you explain why neutrons have not been observed as primary cosmic-rays?
   Hint: look at the properties of neutrons. Justify your answer by small estimative calculations.

c) In more detail, the galactic magnetic field is inhomogenous and the propagation is more random. What would be the fundamental difference of the direction distribution of neutral cosmic rays compared to the direction distribution of charged cosmic-ray primaries as seen on Earth?

3. **Revision of Cosmic-rays: Lecture 2-3 and the exercise 2-3**
Familiarize and work through the lecture slides and the model answers of exercise 2 together with your own answers. Use external sources whenever needed or incase you want to study more. Give answers by using few words and sentences or even figures, formulas only when required. Try to justify your answers.

a) Understand the difference of differential and integrated intensity and the features of the cosmic-ray spectrum. Understand the energy scales involved. Understand the two main measurement techniques of primary cosmic-rays: direct and indirect. For example, you may ask yourself:
- what is meant by the knee, the ankle and the GZK-cut? what is a spectrometre? what can a space-borne spectrometre (as they exist in the present) measure about primary cosmic-ray flux and what can't it? what is an EAS array? what do the detectors of a ground array measure, i.e. what do they detect? what do the fluorescent detectors measure? why are the ground arrays usually organized into a grid-like form? why do EAS detectors exist (give examples of scientific goals)? why is AUGER array larger than KASCADE array, i.e. what are the differences of the EAS they are designed to measure?
Think about other questions relevant.

b) Understand the basis of *longitudinal shower development*: Understand how the shower particle numbers develop as a function of shower depth. Understand the energy and mass dependence.
For example:
- how does the altitude above sea level [in km] and the shower depth [in g/cm] compare to each other?
- compare the results of the Heitler model,

$$N_{max} = E_0/E_c, \mathrm{X_{max}} = \lambda \mathrm{log_2(E_0/(AE_c))}$$

, to that of the results of measurements and more sophisticated air shower models as given in the lecture formulae and plots: -what does the Heitler model describe properly? -where does the model fail?
- what are the most significant differences of proton and heavy-nuclei initiated air-showers?
- how is the shower depth proportional to the primary cosmic ray energy?

c) Understand in a general way the cosmic-ray sources and their propagation.
For example:
- what do all the acceleration models share in common?

Think about other questions relevant.

d) General:
Figure-reading techniques:
- read and understand the labels of axis and their scale.
- read and understand each curve or symbol plotted.
- study and compare the curves and make conclusions.

Definitions etc.
- what is meant by particle decay and life-time?
- what is meant by particle interaction? what is meant by interaction mean free path? how does the interaction mean free path change in materials of different densities?
- what is meant by acceptance of a detector?
- what other definitions and terms would be good to revise?

What is meant by a term scientific model? What is meant by a term scientific measurement?

Note: no written answer is required to gain a point from this task (task number 3)! Just let the assistants know if you tried to do it.