Phys106, II-Semester 2019/20, Tutorial 4, Fri 31.1.

Work in teams of three. Do "Stages" in the order below. When all teams finished a stage, make sure all students at your table understand the solution and agree on one by using the board (in Studio-Air), or paper sheets (in L1).

For this tutorial, you may find the following list of physical constants convenient:

- $h = 6.62607004 \times 10^{-34}$ J s
- $\hbar = 1.054571800 \times 10^{-34}$ J s
- $e = 1.60217662 \times 10^{-19}$ C
- $c = 2.99792458 \times 10^{8}$ m/s

Stage 1

(i) How does an X-ray tube work? Which two components do the generated X-ray spectra have and why?

(ii) If you find a minimal X-ray wavelength of 0.04 nm, what was the acceleration voltage for the electrons in the tube?

(iii) Work with each other on the table through the lecture part regarding X-ray diffraction (XRD) to make sure you all understand how it works.

(iv) In an XRD analysis, a sample which we suspect to be partially crystalline is ground into powder and mounted as shown in Fig. 1. We illuminate it with a mono-chromatic (=single wavelength) X-ray source at $\lambda_{XR} = 0.10$ nm. We then rotate the sample and the X-ray detector as shown in (a) and record the indicated spectrum in (b) at certain scattering angles θ. Infer the lattice constant d of the crystals in the sample, ignoring the fact that multiple-Bragg planes might exist in the crystal (we consider only one). Why do we grind the sample into powder?

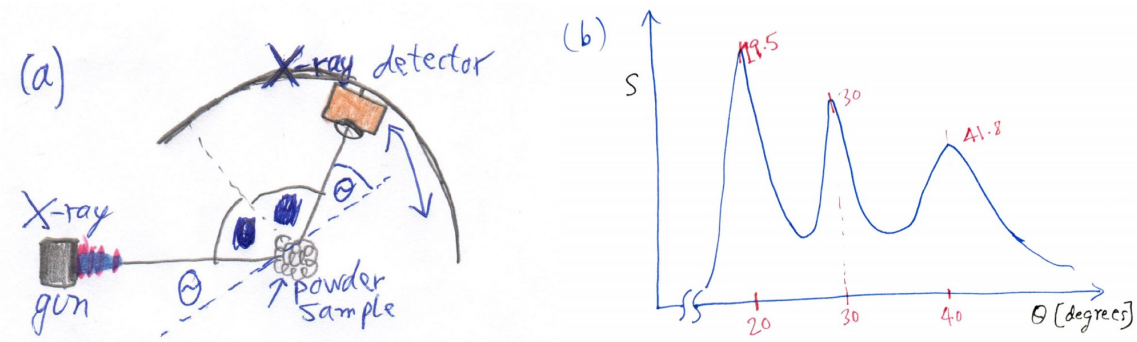

Figure 1: XRD scheme (a) setup, (b) recorded X-ray signal S.

Stage 2 Discuss the following questions:

(i) Why is Compton-scattering from electrons best seen with X-rays?

(ii) Why do Compton-scattering spectra also show an unshifted part (at the same wavelengths as the incoming X-ray)?

(iii) Why can a photon not produce an electron-positron pair in free space?

Stage 3 The top-quark is an exotic elementary particle akin to up-quarks which are an important part of the proton, but much heavier with a rest mass of $m_t = 3.07402 \times 10^{-25}$ kg (compare the mass of a proton/electron of $m_p = 1.672 \times 10^{-27}$ kg). For which frequency of γ-ray photon could the photon annihilate in top-anti-top pair production (in the presence of a heavy nucleus)? Suppose you want to create this γ-ray akin to the X-ray tube by first accelerating an electron between a cathode and an anode, what voltage do you need between these?