PAUL SCHERRER INSTITUT PSI

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Synchrotron Radiation — Exam

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Name

- You have 90 minutes.
- You may use all course material that you have printed or downloaded on your computer/tablet, as well as your notes.
- On-line connections are not allowed. Turn Wi-Fi off, put your tablet in airplane mode, and hand in your mobile phone to the instructor.
- Justify your answers, and write out the calculations. If you need additional space, you may attach additional sheets to the exam.
- You can get a total of 20 points. If you like the challenge, you can earn additional "star" points by solving the exercises indicated by a ★.
- To pass the exam, it is sufficient to solve the regular questions. Star questions may go beyond what was covered in the course. Don't get hung up on these, and if you are short in time, finish the regular questions first.
- If your calculator cannot evaluate Bessel functions, you may read approximate values off the graphs in the lecture.
- Good luck!

1 Synchrotron Radiation (1P.)

Synchrotron radiation...(Check all that apply: more than one answer is possible.)

- ◯ ...can be calculated from Maxwell's equations, without the need of material constants
- ◯ ...is emitted at much longer wavelengths, as compared to cyclotron radiation
- ◯ ...is used by scientists in numerous disciplines, including semiconductor physics, material science and molecular biology
- ◯ ...is emitted by the protons in LHC

2 Undulators (1P. + 1P.⋆)

Which options exist to tune the photon energy of coherent radiation emitted by a permanent magnet undulator? (Give two options.)
★ How is the critical photon energy from each dipole in the undulator affected by these two tuning methods? What are the consequences?

3 Cosmic Electron (3P. + 1P.⋆)

A cosmic electron with an energy of 1 GeV enters an interstellar region with a magnetic field of 1 nT. Calculate

- The radius of curvature
- The critical energy of the emitted synchrotron radiation
- The energy emitted in one turn

⋆ How would you measure this radiation?

4 Undulator (4P.)

An undulator has a length of 5.1 m and a period λ_u = 15 mm. The pole tip field is B_t = 1.2 T. For a gap of g = 10 mm, calculate

- the peak field on axis B_0
- the undulator parameter K

The undulator is installed in a storage ring with an electron beam energy of E = 3 GeV. Assume electron a beam current of 500 mA, beam emittances of σ_x = 1 nm and σ_y = 1 pm, alpha functions $\alpha_x = \alpha_y = 0$, beta functions of β_x = 3.5 m and β_y = 2 m, and calculate

- the wavelength of radiation emitted on axis
- the relative bandwidth
- the photon flux (*Hint:* if your calculator cannot evaluate Bessel functions, you may extract the value of $Q_n(K)$ from the plot in the lecture.)
- the electron beam size and divergence
- the effective source size and divergence
- the brilliance of the radiation at the fundamental wavelength

5 Emittance and Energy Spread (2P.)

The equilibrium emittance of an electron bunch in a storage ring occurs when factors increasing ε are compensated by those reducing ε.

- Which effect increases the horizontal emittance ε_x?
- Which effect decreases the horizontal emittance ε_x?
- Which effect increases the vertical emittance ε_y?
- Which effect decreases the vertical emittance ε_y?

6 Instrumentation (1P.)

How would you measure the vertical emittance in a storage ring?

7 Top-up Operation (1P. + 1P.⋆)

What are the advantages of top-up operation? What difficulties have to be overcome to establish top-up in a storage ring? (Give one advantages and one difficulty for 1P., give one more advantages and one more difficulty for 1P.⋆.)

8 Detectors (1P. + 1P.⋆)

Name two or more advantages of semiconductor detectors, as compared to Röntgen's photographic plates! (Give two advantages for 1P., give two more advantages or disadvantages for 1P.⋆.)

9 Crystals (1P.)

Which of the following are crystalline? More than one answer is possible.

- ◯ Sapphire
- ◯ Fused silica
- ◯ Snowflakes
- ◯ Paracetamol (Acetaminophen) powder in capsules

10 X-Ray Absorption (1P.)

What is the dominant process for X-Ray absorption of

- 10 keV photons
- 1 MeV photons
- 100 MeV photons

in matter?

11 Diffraction (3P.)

A scientist wants to record a diffraction pattern of crystalline tungsten at a photon energy of 20 keV. What is the optimum thickness of the crystal, that maximizes the intensity of the diffracted spot? Derive the formula for the intensity I of the diffracted spot as a function of thickness z, and solve for $dI/dz = 0$. Material constants can be found in the X-Ray Data Booklet.

12 X-Ray Absorption Spectroscopy (1P.)

X-Ray Absorption Spectroscopy can be used to determine...(More than one answer is possible.)

- ◯ the presence of elements that occur in very low concentration
- ◯ the chemical state of atoms in the sample
- ◯ the transverse coherence of the X-ray beam
- ◯ the doping of semiconductors

13 Undulator Radiation (3P.⋆)

★ Derive the formula for the fundamental wavelength of undulator radiation emitted at a small angle θ:

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

from the condition of constructive interference of the radiation emitted by consecutive undulator periods!

14 Photon Diagnostics (3P.⋆)

★ A.J. Kwak, the representative of Great Waterland Photonics, presents you their newest device for your synchrotron:
"This novel X-ray spectrometer uses Bragg refraction from a silicon crystal to cover a broad spectral range from 10 to 16 keV. Rather than performing a cumbersome scan to record the spectrum, a silicon strip detector records the entire spectrum simultaneously. The device works without moving parts, ensuring the highest possible stability and reliability. A novel stress-free mount for the Bragg crystal further adds to this, allowing to reach a resolution of 20 eV"
You have just secured funding for upgrading the photon diagnostics for your synchrotron. Would you buy this spectrometer? Why?