Synchrotron Radiation — Exercises 2

Rasmus Ischebeck

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1 Storage Rings

Describe the characteristics of the following:

- First generation synchrotron radiation light source
- Second generation synchrotron radiation light source
- Third generation synchrotron radiation light source
- Fourth generation synchrotron radiation light source (diffraction-limited light source)

Answers

- 1st Generation: storage rings built for particle physics, and used parasitically for synchrotron radiation
- 2nd Generation: storage rings built for the purpose of generating synchrotron radiation
- 3rd Generation: optimized rings for low emittance; insertion devices (wigglers and undulators), top-up operation
- Generation 4a: free electron lasers, and Generation 4b: diffraction limited storage rings; the latter make use of an optimized beam optics to minimize dispersion in the dipoles to reduce the horizontal emittance.

2 Damping

Why is the horizontal emittance often larger than the vertical emittance in an electron storage ring? What is the situation in a proton storage ring?

Answers

Both horizontal and vertical emittances are damped by the synchrotron radiation that the electrons emit (radiation damping). In the horizontal plane, however, the quantum nature of the synchrotron emission leads to an emittance growth. When these two effects reach the same magnitude, the electron beam reaches an equilibrium emittance.
In a proton storage ring, the damping times are typically in the order of several hours to days. Therefore, the emittance stays very close to the injection emittance, and the equilibrium between radiation damping and quantum excitation is never reached.

3 Applications

What applications for industry are there to synchrotrons?

Answers

The primary application of synchrotron radiation for industrial users is structure determination for the pharmaceutical industry. There are also applications of synchrotrons in material science that can be interesting to industrial users.

4 Top-up Operation

What are the advantages of top-up operation? What difficulties have to be overcome to establish top-up in a storage ring?

Answers

Keeping the beam current in a storage ring constant results in a uniform thermal load, such that a much better stability can be reached. To set up top-up in a storage ring, one needs first to accelerate the particles to the final energy in the pre-accelerator chain, and then one needs a mechanism to inject the additional electrons into the acceptance region in the phase space of the bunches.

5 Detection

What possibilities exist to detect X-Rays? How has the development of X-ray detectors influenced experiments at synchrotron sources?

Answers

The two primarily used detectors in synchrotrons are direct semiconductor detectors, and scintillators coupled to visible-light cameras. The immediate availability of the data in digital form makes numerical treatment of the data possible, which is essential to techniques such as tomography and ptychography, and to the reconstruction of diffraction data.

6 Monochromators

What dispersive element is used to monochromatize X-Rays? What differences exist to monochromators for visible light?

Answers

The lattice of single crystals is used in monochromators for X-rays. In comparison to monochromators for visible light, which disperse the beam in a grating, the Bragg condition for crystal diffraction puts a restraint on the angle of both the incoming and the outgoing beam.

7 Crystals

Which of the following are crystalline? More than one answer is may be correct.

⊕ silicon wafers for IC production

⊖ viruses

⊕ snowflakes

⊖ the protein in an egg

8 Stability

A user at your synchrotron light source has to make a long-duration scan of a sample, and needs very stable conditions. Mention at least two aspects of the storage ring that must be ensured for this measurement!

Answers

- stable beam position
- stable beam size
- stable beam current
- stable beam energy

9 Instrumentation

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

Answers

The vertical emittance can be deduced from the beam size, because the beam optics is given by the ring. The beam size can be measured from synchrotron radiation emitted in a dipole magnet. This can be either imaged (X-ray imagers, i.e. pinhole cameras, typically have a better resolution than visible-light cameras), or an interference pattern from the synchrotron radiation can be used to evaluate the source size.