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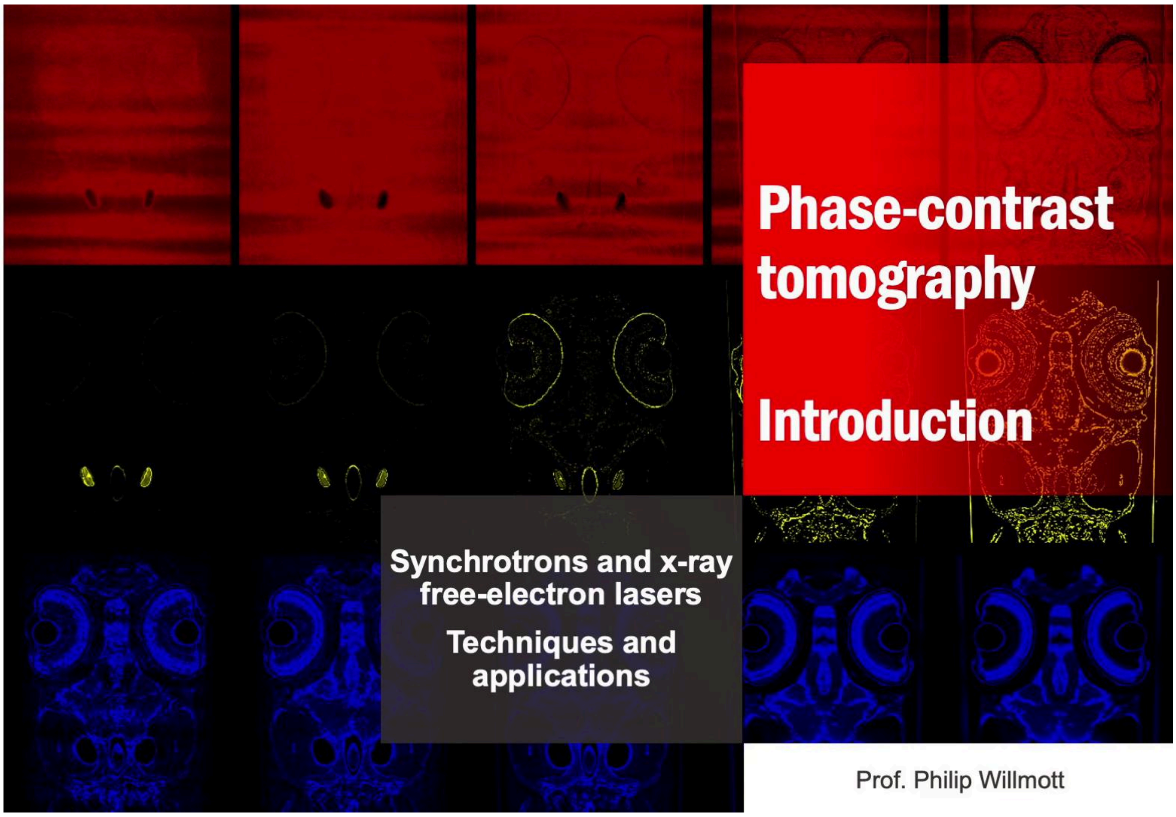
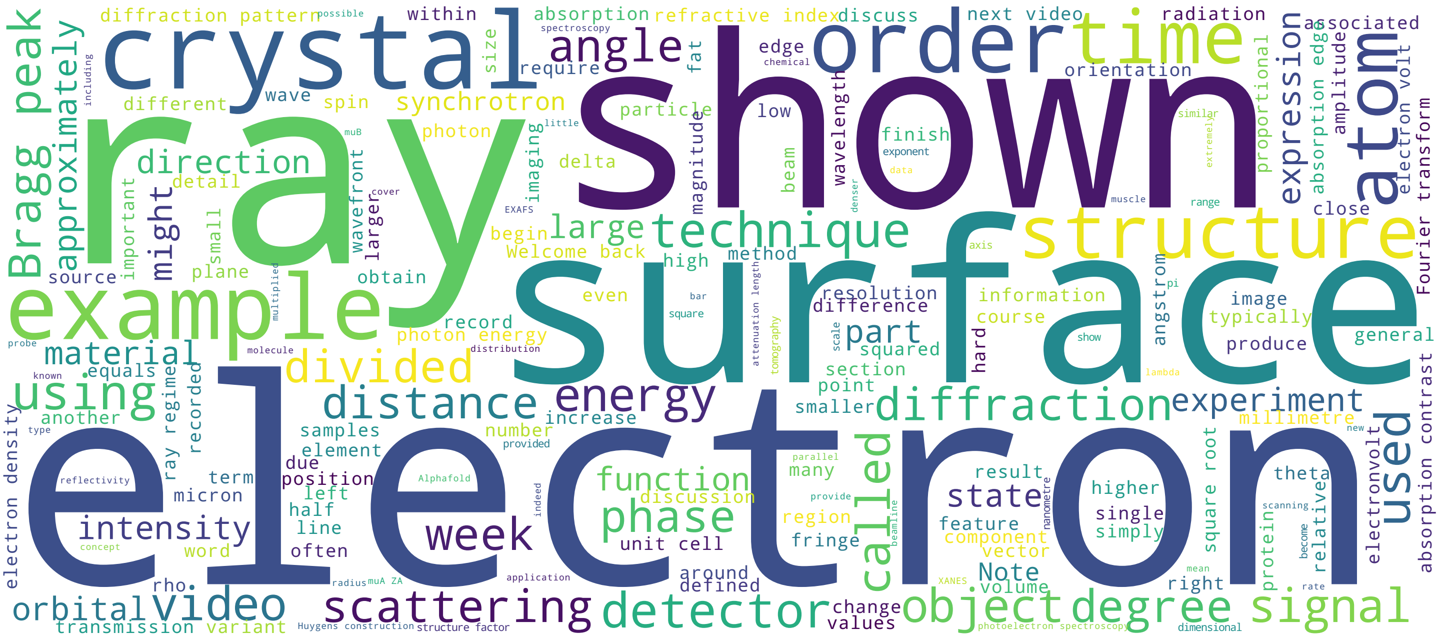


Prof. Philip Willmott



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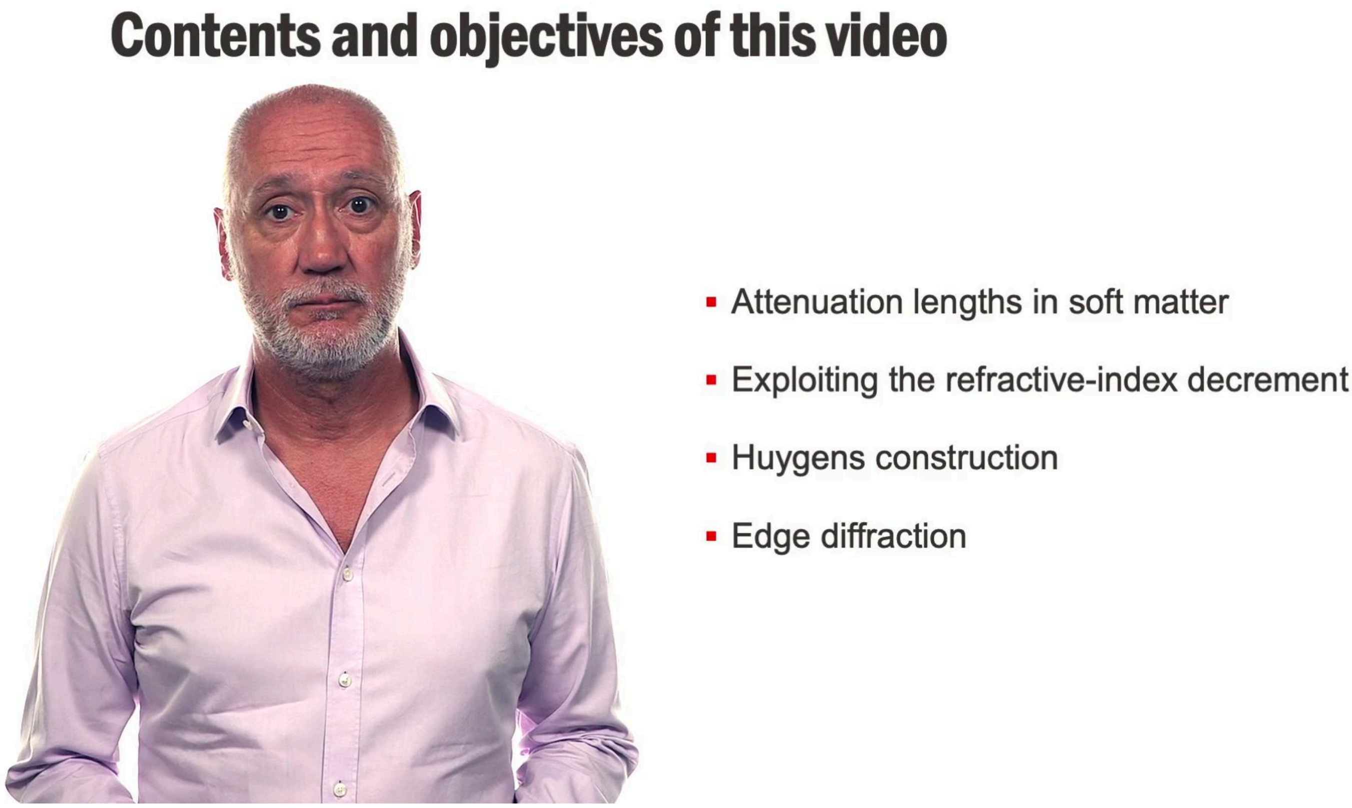


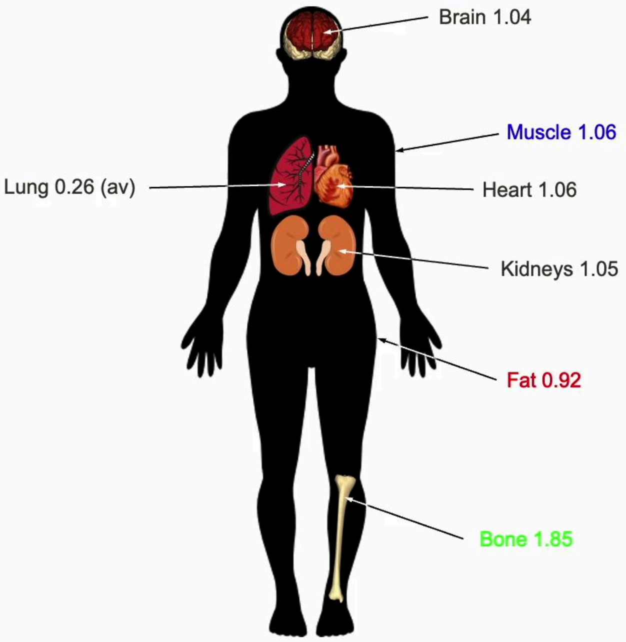
Welcome back to this introductory course on Synchrotron and XFEL radiation. In this second section of the fifth week, we will cover phase contrast tomography, a variant of standard tomography used primarily in experiments on soft-matter samples for which the absorption contrast is weak. In such situations, we will see qualitatively that subtle fluctuations in the refractive index can come to the rescue where absorption contrast fails. To understand this more deeply, we will consider, first the Huygens construction, especially in the context of edge diffraction.

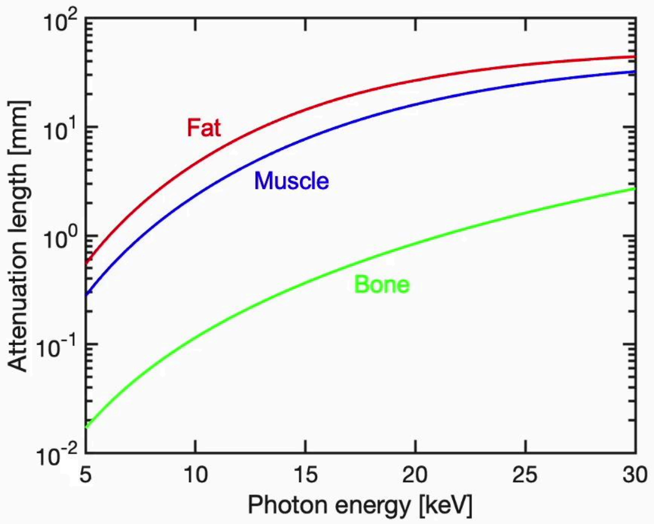
Notes

Summary

0m 05s

Absorption contrast from soft matter





With the exception of our bones, which are denser and our lungs which on average are less dense, most of all the body's components have a specific gravity very close to 1g/cm³. Even muscle, which sports people often say is much denser than fat, is in reality only about 15% denser. The ratio of attenuation lengths of muscle and fat in the hard X-ray regime is approximately 1.5. Now, this might seem to be more than enough until one considers the difference in transmission for samples which have characteristic lengths significantly smaller than their attenuation lengths, which are a few centimetres in the hard X-ray regime at around 25 kilo electron volts.

Notes

Summary

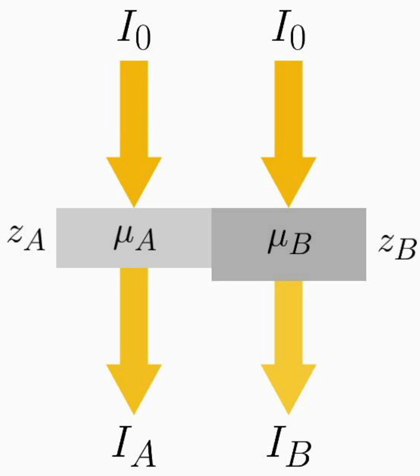
0m 44s

Absorption contrast from soft matter

$$C_a = \frac{I_A - I_B}{I_A}, \quad (I_A > I_B)$$
$$= \frac{\exp(-\mu_A z_A) - \exp(-\mu_B z_B)}{\exp(-\mu_A z_A)}$$
$$= 1 - \exp(\mu_A z_A - \mu_B z_B)$$

If $\mu_A z_A,\ \mu_B z_B \ll 1$

$$C_a \approx \mu_B z_B - \mu_A z_A$$



e.g. A = fat (0.92 g/cm^3) and B = muscle (1.06 g/cm^3)
20-keV radiation
$z_A = z_B$
C_a = z [mm]/16.1 – z [mm]/26.7
z = 1 mm, C_a = 0.025

Okay, so let's formalise absorption contrast. This is given by the difference in transmission intensity of two differently absorbing materials divided by the transmission intensity of the weaker absorber. So assuming sample component A the weaker absorber has an absorption coefficient mu A and absorbs through a depth of ZA. And similarly for component B, the absorption contrast CA is given by this expression. So if we divide the top and the bottom by the exponent of minus muA ZA we obtained the expression of CA being equal to 1 minus the exponent of muA, ZA minus muB, ZB. Okay. Now, if both muA ZA and muB ZB are much smaller than unity, that is, both components are very weak absorbers, then our expression for CA further simplifies to muB ZB minus mu A ZA. So let's consider what might we might expect from a biopsy of a one millimetre thick sample of fat and muscle. One millimetre is much smaller than either attenuation lengths of fat and muscle. Hence we can use our simplified expression to obtain CA is approximately equal to 0.025 or 2.5%, not much at all. Most bodily components that are not bone differ in attenuation coefficient, even less than due muscle and fat. Hence absorption contrast even for samples that might be a centimetre thick or so can be impractically small.

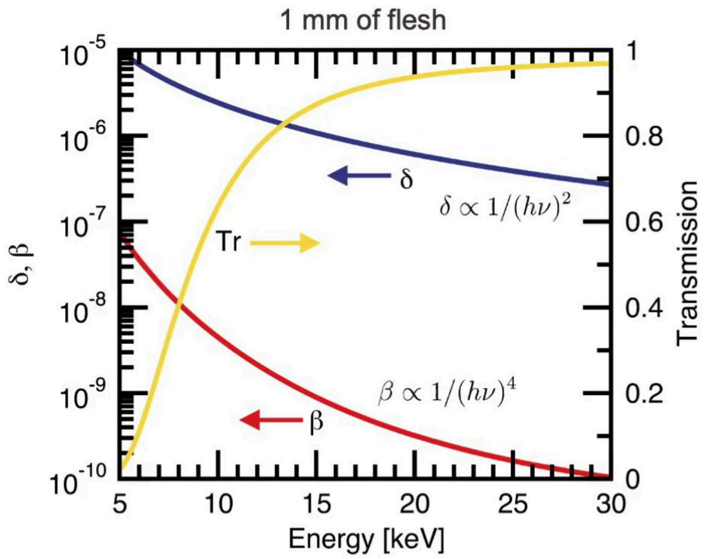
Notes

Summary

1m 30s

Exploiting the refractive-index decrement

- δ: describes refraction (bending capability, change in v_p)
- β: describes absorbing strength
- β becomes increasingly weaker than δ with increasing photon energy
- How exactly does δ provide contrast?



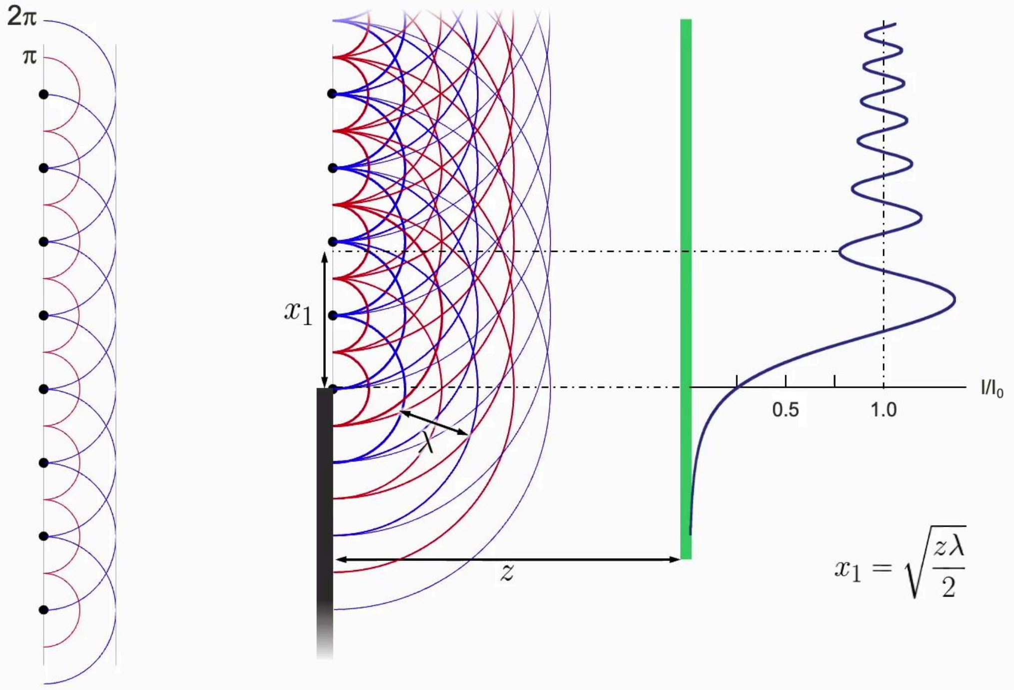
So how might we circumvent this problem? The answer lies in the refractive index of condensed matter in the x ray regime. As you will remember, hopefully, from the first part of this twin course, the complex refractive index has a real part 1 minus delta and an imaginary component i beta. The latter is responsible for absorption, the former for refraction. Values for delta, the so-called refractive index decrement and beta, the absorption index plus the transmission through one millimetre of flesh are provided here on the right. Importantly, in the high-energy regime, the transmission is so high and hence absorption contrast unacceptably weak, but in general, the refractive index decrement drops off only with the inverse square of the photon energy, in contrast to the absorption index, which decreases as h nu to the minus four. Okay, but how do subtle changes in the refractive index provide some kind of imaging contrast?

Notes

Summary

3m 26s

Huygens' construction



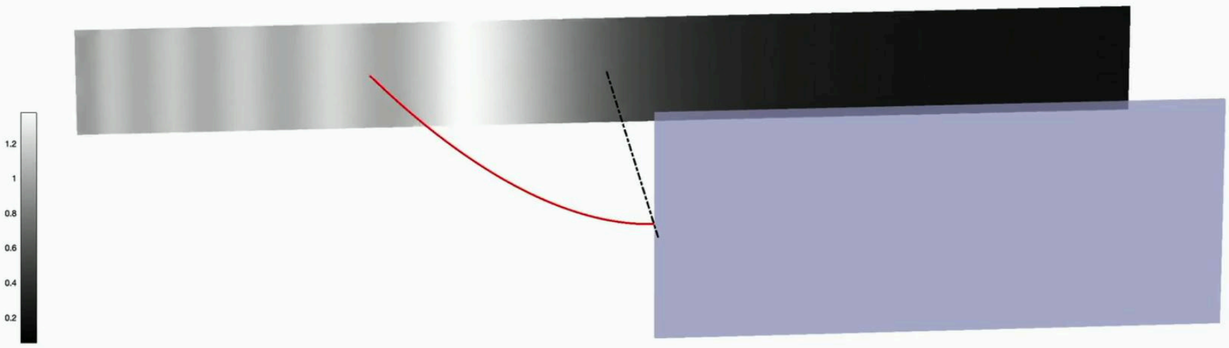
Before we answer this question, we are briefly going to visit Huygens Construction, which in its essence states that every point along a wavefront is itself a source of emanating spherical wavelets. These mutually interfere, resulting in the next wavefront and so on. Now, in the case of a plane wave, this continues unchanged ad infinitum but now let's consider what happens if we introduce an opaque screen that partially blocks the propagating wave. Those wavelet sources that haven't been blocked carry on in their happy way as before, while contributions to the subsequent wavefronts are lost from the blocked regions. If we place a detector at a distance Z downstream of the screen, the intensity profile doesn't show a perfectly sharp shadow profile, but instead consists of a set of fringes with the first minimum at a distance X1 from the edge of the screen. Geometrically these fringes occur because the wavefront, which would otherwise be a flat plane, misses contributions from the missing wavelets where the screen is, which add to the sum both constructively and destructively. So it emerges that the position of the first fringe is given by the square root of Z lambda divided by 2. For one angstrom radiation and a distance of half a metre X1 is equal to five microns.

Notes

Summary

4m 37s

Edge diffraction



Take-home message here: wave nature of light causes shadow edges to become blurred (or modulated) the further away one records that shadow from the absorbing object that produced it

So for a given monochromatic incident beam, if we move an area detector from being directly butted up against the opaque screen to further downstream, we can expect the fringe pattern to expand at a rate which is proportional to the square root of the screen detector distance. So the take-home message from our discussion of Huygens construction is thus that the wave nature of light causes shadow edges to become modulated and blurred the further away one records that shadow from the absorbing object that produces it.

Notes

Summary

6m 16s

In the next video…

As we will see in the next video, an object placed in the beam needn't be completely or even partially opaque to induce fringes in detectors placed downstream from that object, but only that it induces a phase shift in that part of the wavefront that is propagated through it. We will also discuss the Fraunhofer and Fresnel conditions and how we produce contrast from phase objects, that is, objects with little or no absorption, but which do induce phase shifts in the wavefront.

Notes

Summary

6m 55s