Today's Outline - September 28, 2016

Today's Outline - September 28, 2016

- Ideal refractive surface

Today's Outline - September 28, 2016

- Ideal refractive surface
- Fresnel lenses and zone plates

Today's Outline - September 28, 2016

- Ideal refractive surface
- Fresnel lenses and zone plates
- Research papers on refraction

Today's Outline - September 28, 2016

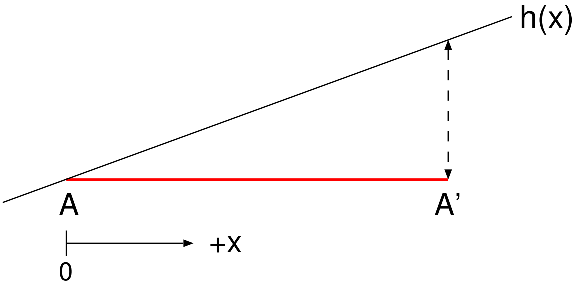
- Ideal refractive surface
- Fresnel lenses and zone plates
- Research papers on refraction
- Homework #2 solutions

Today's Outline - September 28, 2016

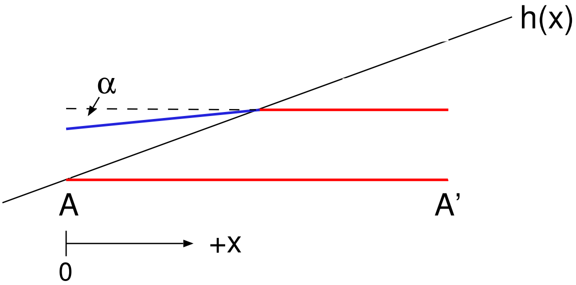
- Ideal refractive surface
- Fresnel lenses and zone plates
- Research papers on refraction
- Homework #2 solutions

Homework Assignment #03:
Chapter 3: 1, 3, 4, 6, 8
due Wednesday, September 05, 2016

Ideal interface profile

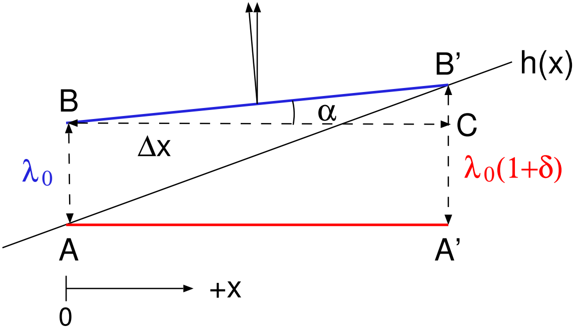


Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α.

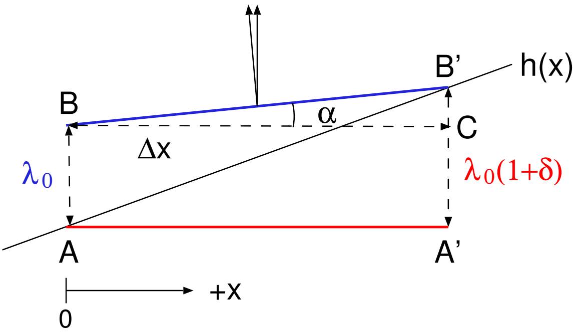
Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α.

Follow the path of two points on the wavefront, A and A' as they propagate to B and B'.

Ideal interface profile

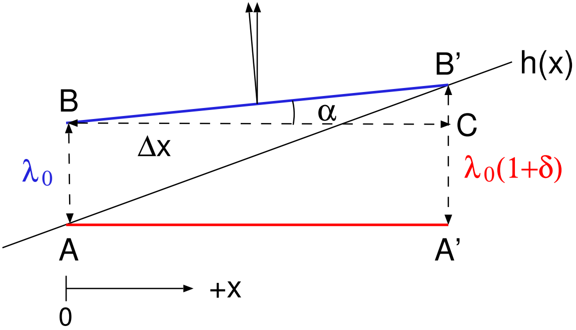


from the $AA'B'$ triangle

The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α.

Follow the path of two points on the wavefront, A and A' as they propagate to B and B'.

Ideal interface profile

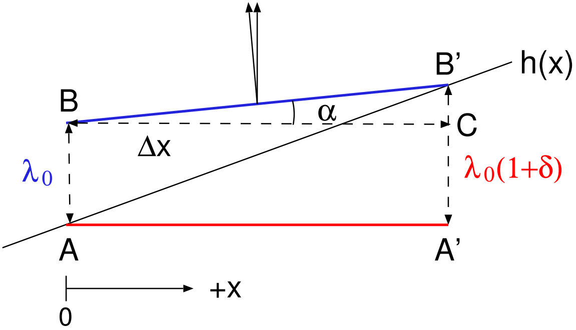


The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α. Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x$$

Ideal interface profile

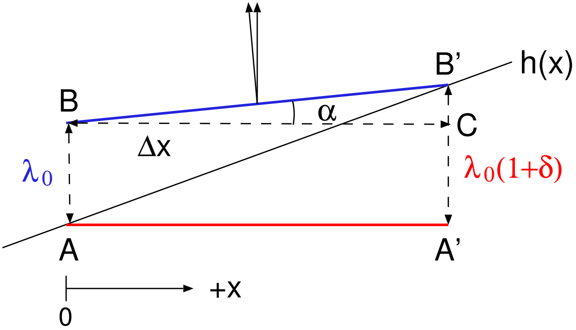


The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α. Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x \quad \longrightarrow \quad \Delta x \approx \frac{\lambda_0}{h'(x)}$$

Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α.

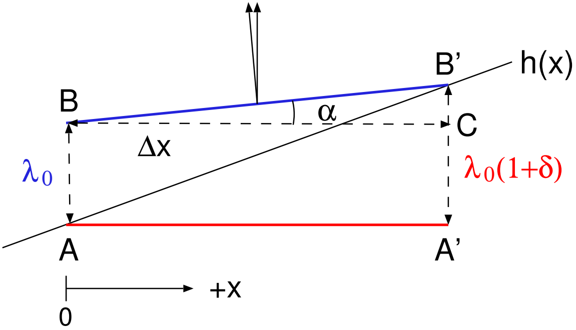
Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

from the $AA'B'$ triangle

and from the BCB' triangle

$$\lambda_0 \left(1 + \delta\right) = h'(x)\Delta x \quad \longrightarrow \quad \Delta x \approx \frac{\lambda_0}{h'(x)}$$

Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α. Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

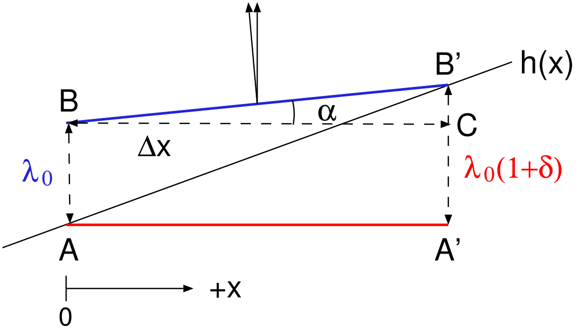
from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x \longrightarrow \Delta x \approx \frac{\lambda_0}{h'(x)}$$

and from the BCB' triangle

$$\alpha(x) \approx \frac{\lambda_0 \delta}{\Delta x}$$

Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α.

Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

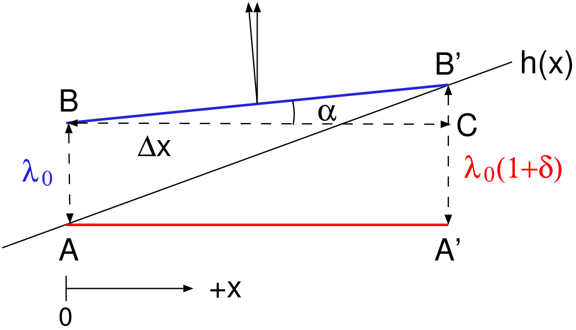
from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x \longrightarrow \Delta x \approx \frac{\lambda_0}{h'(x)}$$

and from the BCB' triangle

$$\alpha(x) \approx \frac{\lambda_0 \delta}{\Delta x} = h'(x)\delta$$

Ideal interface profile



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α. Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

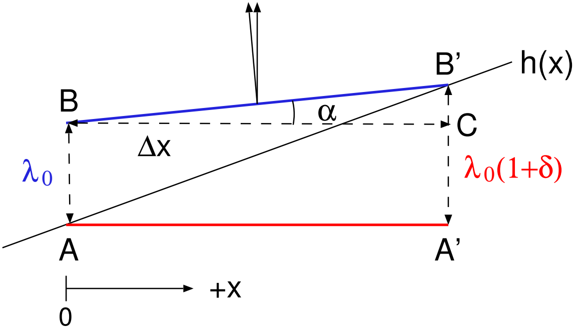
from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x \quad \longrightarrow \quad \Delta x \approx \frac{\lambda_0}{h'(x)}$$

and from the BCB' triangle

$$\alpha(x) \approx \frac{\lambda_0 \delta}{\Delta x} = h'(x)\delta$$

using $\Lambda = \lambda_0/\delta$



The wave exits the material into vacuum through a surface of profile $h(x)$, and is twisted by an angle α. Follow the path of two points on the wave-front, A and A' as they propagate to B and B'.

from the $AA'B'$ triangle

$$\lambda_0 (1 + \delta) = h'(x)\Delta x \quad \longrightarrow \quad \Delta x \approx \frac{\lambda_0}{h'(x)}$$

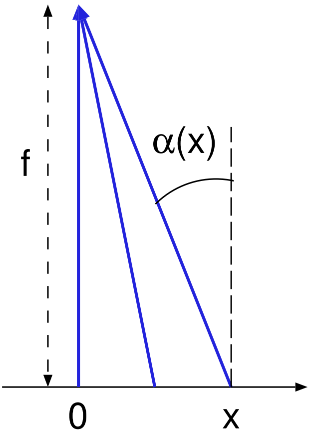
and from the BCB' triangle

$$\alpha(x) \approx \frac{\lambda_0 \delta}{\Delta x} = h'(x)\delta = h'(x)\frac{\lambda_0}{\Lambda}$$

using $\Lambda = \lambda_0/\delta$

Ideal interface profile

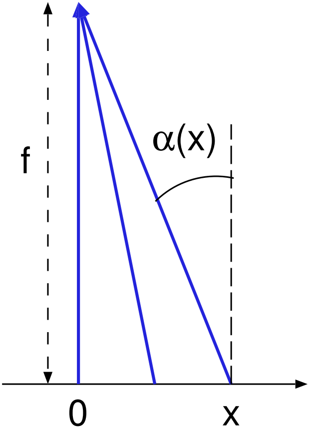
If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis



Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

$$\alpha(x) = \frac{x}{f}$$



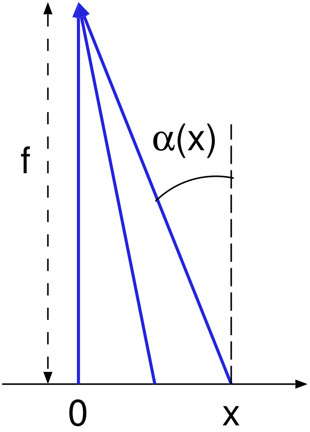
Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f}$$



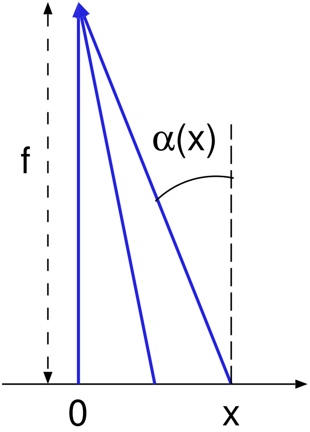
Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f} \quad \longrightarrow \quad \frac{h'(x)}{\Lambda} = \frac{x}{f\lambda_0}$$



Ideal interface profile

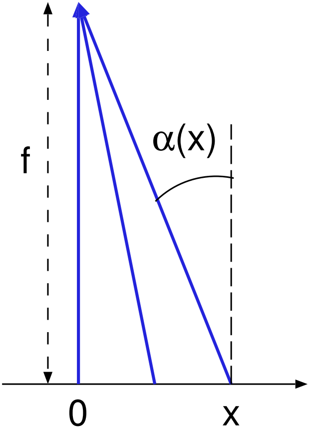
If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f} \quad \longrightarrow \quad \frac{h'(x)}{\Lambda} = \frac{x}{f\lambda_0}$$

this can be directly integrated



Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

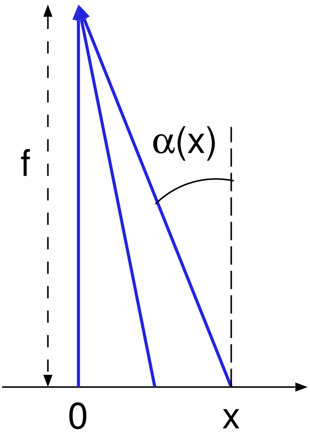
$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f} \quad \longrightarrow \quad \frac{h'(x)}{\Lambda} = \frac{x}{f\lambda_0}$$

this can be directly integrated

$$\frac{h(x)}{\Lambda} = \frac{x^2}{2f\lambda_0}$$



Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

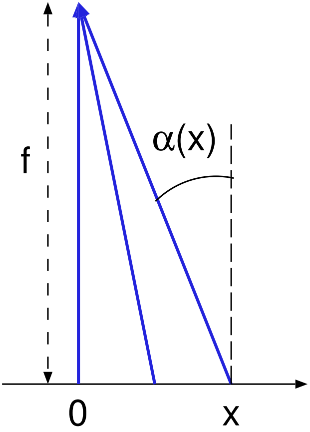
$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f} \longrightarrow \frac{h'(x)}{\Lambda} = \frac{x}{f\lambda_0}$$

this can be directly integrated

$$\frac{h(x)}{\Lambda} = \frac{x^2}{2f\lambda_0} = \left[\frac{x}{\sqrt{2f\lambda_0}}\right]^2$$



Ideal interface profile

If the desired focal length of this lens is f, the wave must be redirected at an angle which depends on the distance from the optical axis

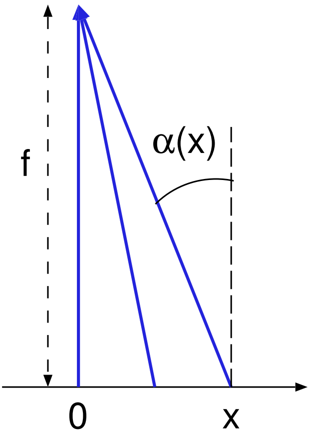
$$\alpha(x) = \frac{x}{f}$$

combining, we have

$$\frac{\lambda_0 h'(x)}{\Lambda} = \frac{x}{f} \quad \longrightarrow \quad \frac{h'(x)}{\Lambda} = \frac{x}{f\lambda_0}$$

this can be directly integrated

$$\frac{h(x)}{\Lambda} = \frac{x^2}{2f\lambda_0} = \left[\frac{x}{\sqrt{2f\lambda_0}}\right]^2$$



a parabola is the ideal surface shape for focusing by refraction

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)}$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta} \frac{x^2}{h(x)}$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2\Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2\Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

$$h(x) = \sqrt{R^2 - x^2}$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

$$h(x) = \sqrt{R^2 - x^2} \qquad \text{and for } x \ll R \qquad h(x) \approx R\left(1 - \frac{1}{2}\frac{x^2}{R^2}\right)$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

$$h(x) = \sqrt{R^2 - x^2} \qquad \text{and for } x \ll R \qquad h(x) \approx R\left(1 - \frac{1}{2}\frac{x^2}{R^2}\right)$$

$$x^2 = R^2 - h^2(x) \approx R^2$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

$$h(x) = \sqrt{R^2 - x^2} \qquad \text{and for } x \ll R \qquad h(x) \approx R\left(1 - \frac{1}{2}\frac{x^2}{R^2}\right)$$

$$x^2 = R^2 - h^2(x) \approx R^2 \qquad \text{so we have} \qquad f \approx \frac{R}{2\delta}$$

Focal length of circular lens

From the previous expression for the ideal parabolic surface, the focal length can be written in terms of the surface profile.

$$f = \frac{x^2 \Lambda}{2\lambda_0 h(x)} = \frac{1}{2\delta}\frac{x^2}{h(x)} \qquad \text{or alternatively} \qquad f = \frac{1}{\delta}\frac{x}{h'(x)}$$

If the surface is a circle instead of a parabola

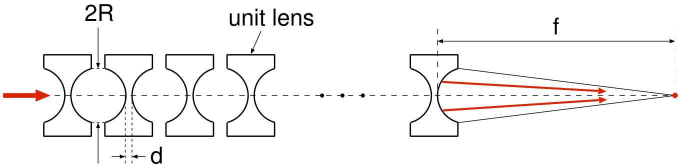
$$h(x) = \sqrt{R^2 - x^2} \qquad \text{and for } x \ll R \qquad h(x) \approx R\left(1 - \frac{1}{2}\frac{x^2}{R^2}\right)$$

$$x^2 = R^2 - h^2(x) \approx R^2 \qquad \text{so we have} \qquad f \approx \frac{R}{2\delta}$$

for N circular lenses

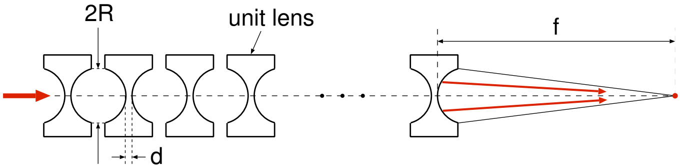
$$f_n \approx \frac{R}{2N\delta}$$

Focussing by a beryllium lens



H.R. Beguiristain, J.T. Cremer, M.A. Piestrup, C.K. Gary, and R.H. Pantell, *Optics Letters,* **27***, 778 (2007).*

Focussing by a beryllium lens

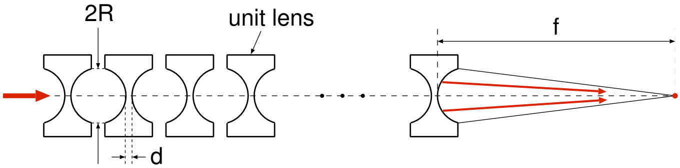


For 50 holes of radius $R = 1\text{mm}$ in beryllium (Be) at $E = 10\text{keV}$, we can calculate the focal length, knowing $\delta = 3.41 \times 10^{-6}$

$$f_N = \frac{R}{2N\delta}$$

H.R. Beguiristain, J.T. Cremer, M.A. Piestrup, C.K. Gary, and R.H. Pantell, *Optics Letters*, **27**, *778 (2007).*

Focussing by a beryllium lens

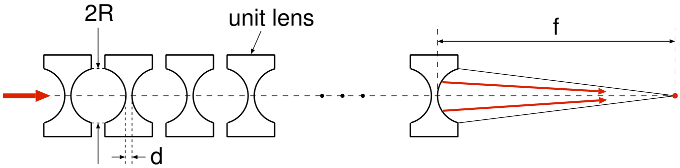


For 50 holes of radius $R = 1\text{mm}$ in beryllium (Be) at $E = 10\text{keV}$, we can calculate the focal length, knowing $\delta = 3.41 \times 10^{-6}$

$$f_N = \frac{R}{2N\delta} = \frac{1 \times 10^{-3}\text{m}}{2(50)(3.41 \times 10^{-6})}$$

H.R. Beguiristain, J.T. Cremer, M.A. Piestrup, C.K. Gary, and R.H. Pantell, *Optics Letters*, **27**, *778 (2007).*

Focussing by a beryllium lens

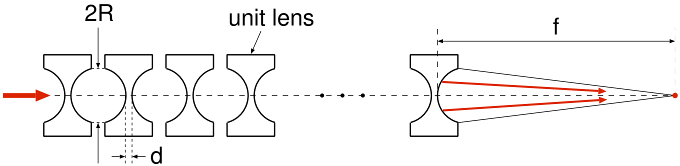


For 50 holes of radius $R = 1\text{mm}$ in beryllium (Be) at $E = 10\text{keV}$, we can calculate the focal length, knowing $\delta = 3.41 \times 10^{-6}$

$$f_N = \frac{R}{2N\delta} = \frac{1 \times 10^{-3}\text{m}}{2(50)(3.41 \times 10^{-6})} = 2.93\text{m}$$

H.R. Beguiristain, J.T. Cremer, M.A. Piestrup, C.K. Gary, and R.H. Pantell, *Optics Letters*, **27**, *778 (2007).*

Focussing by a beryllium lens



For 50 holes of radius $R = 1\text{mm}$ in beryllium (Be) at $E = 10\text{keV}$, we can calculate the focal length, knowing $\delta = 3.41 \times 10^{-6}$

$$f_N = \frac{R}{2N\delta} = \frac{1 \times 10^{-3}\text{m}}{2(50)(3.41 \times 10^{-6})} = 2.93\text{m}$$

depending on the wall thickness of the lenslets, the transmission can be up to 74%

H.R. Beguiristain, J.T. Cremer, M.A. Piestrup, C.K. Gary, and R.H. Pantell, *Optics Letters*, **27**, *778 (2007).*

Variable focal length CRL

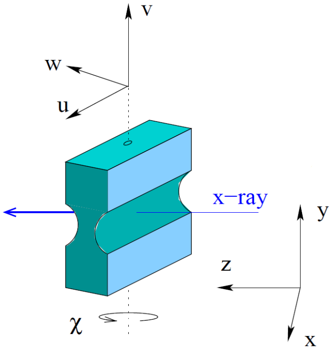
The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL.

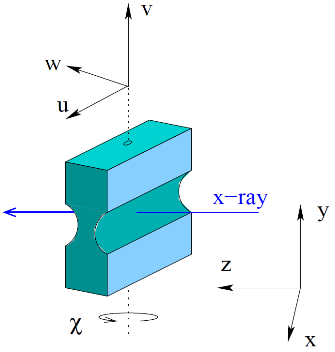


B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL. Rotate by an angle χ about vertical axis

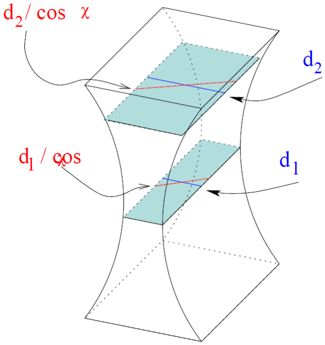


B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL. Rotate by an angle χ about vertical axis giving an effective change in the number of "lenses" by a factor $1/\cos\chi$.



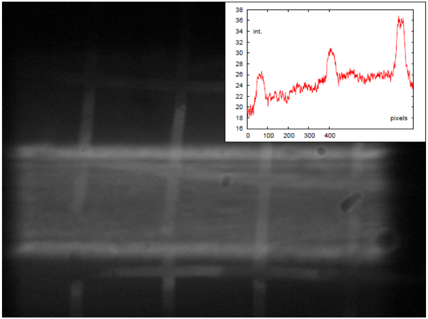
B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL. Rotate by an angle χ about vertical axis giving an effective change in the number of "lenses" by a factor $1/\cos\chi$.

at $E = 5.5$keV and $\chi = 0^\circ$, height is over 120μm

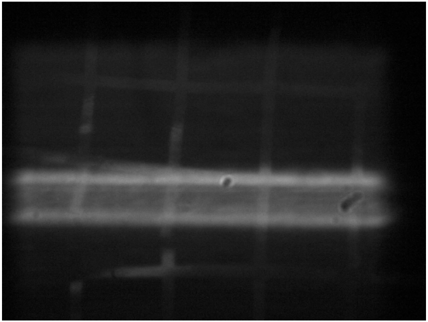


B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL. Rotate by an angle χ about vertical axis giving an effective change in the number of "lenses" by a factor $1/\cos\chi$.



at $E = 5.5$keV and $\chi = 0^\circ$, height is over 120μm

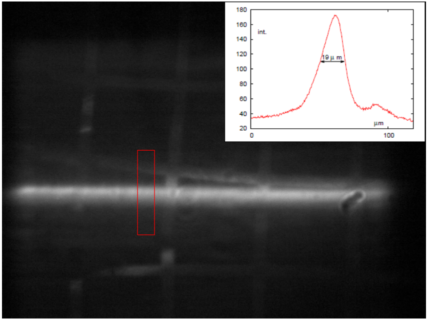
At $\chi = 30^\circ$, it is under 50μm

B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Variable focal length CRL

The compound refractive lenses (CRL) are useful for fixed focus but are difficult to use if a variable focal distance and a long focal length is required.

Start with a 2 hole CRL. Rotate by an angle χ about vertical axis giving an effective change in the number of "lenses" by a factor $1/\cos\chi$.



at $E = 5.5$keV and $\chi = 0^\circ$, height is over 120μm

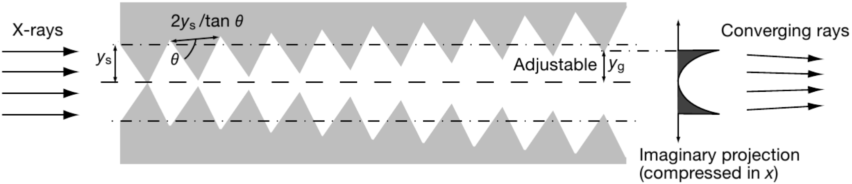
At $\chi = 30^\circ$, it is under 50μm

Optimal focus is 20μm at $\chi = 40^\circ$

B. Adams and C. Rose-Petruck, "X-ray focusing scheme with continuously variable lens", *J. Synchrotron Radiation* **22**, 16-22 (2015).

Alligator-type lenses

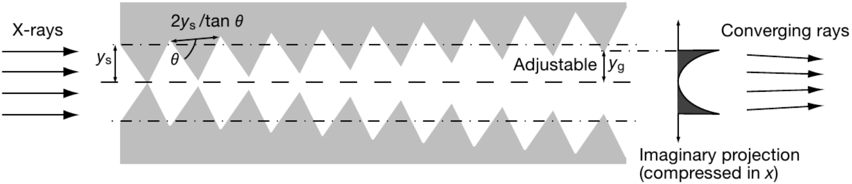
Perhaps one of the most original x-ray lenses has been made by using old vinyl records in an "alligator" configuration.



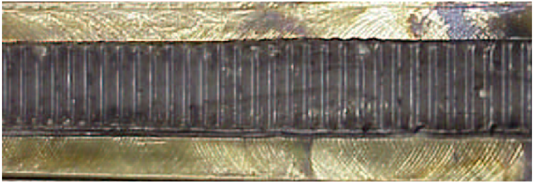
Björn Cederström et al., "Focusing hard X-rays with old LPs", *Nature* **404**, 951 (2000).

Alligator-type lenses

Perhaps one of the most original x-ray lenses has been made by using old vinyl records in an "alligator" configuration.



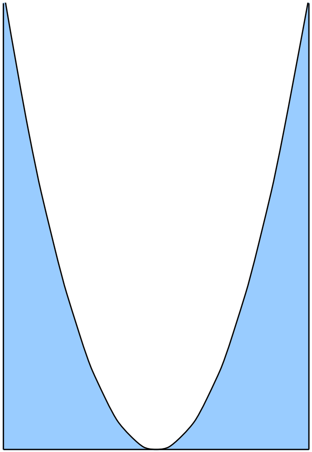
Björn Cederström et al., "Focusing hard X-rays with old LPs", *Nature* **404**, 951 (2000).



This design has also been used to make lenses out of lithium metal.

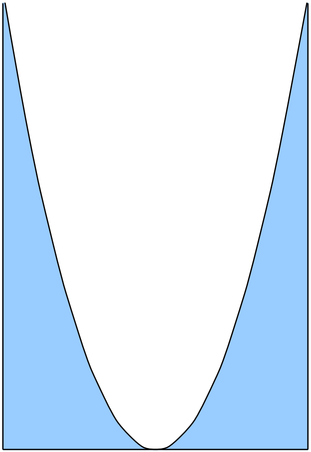
E.M. Dufresne et al., "Lithium metal for x-ray refractive optics", *Appl. Phys. Lett.* **79**, 4085 (2001).

How to make a Fresnel lens



The ideal refracting lens has a parabolic shape (actually elliptical) but this is impractical to make.

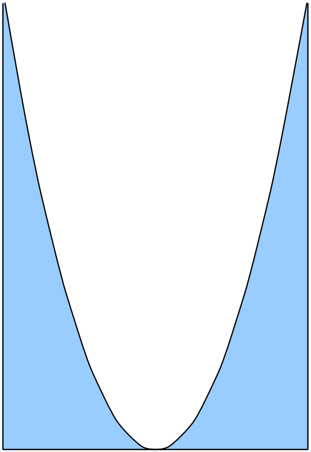
How to make a Fresnel lens



The ideal refracting lens has a parabolic shape (actually elliptical) but this is impractical to make.

$$h(x) = \Lambda \left(\frac{x}{\sqrt{2\lambda_o f}} \right)^2$$

How to make a Fresnel lens

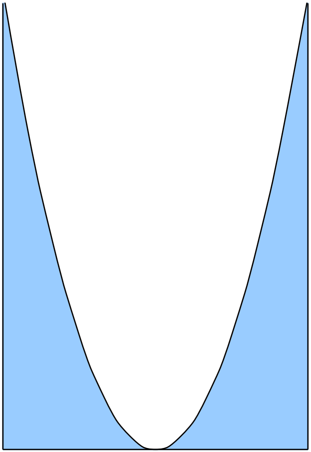


The ideal refracting lens has a parabolic shape (actually elliptical) but this is impractical to make.

$$h(x) = \Lambda \left(\frac{x}{\sqrt{2\lambda_o f}} \right)^2$$

when $h(x) = 100\Lambda \sim 1000\mu$m

How to make a Fresnel lens



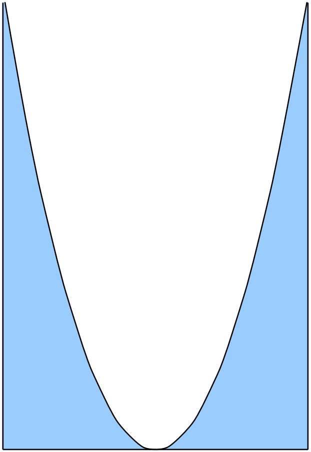
The ideal refracting lens has a parabolic shape (actually elliptical) but this is impractical to make.

$$h(x) = \Lambda \left(\frac{x}{\sqrt{2\lambda_o f}} \right)^2$$

when $h(x) = 100\Lambda \sim 1000\mu\text{m}$

$$x = 10\sqrt{2\lambda_o f} \sim 100\mu\text{m}$$

How to make a Fresnel lens



The ideal refracting lens has a parabolic shape (actually elliptical) but this is impractical to make.

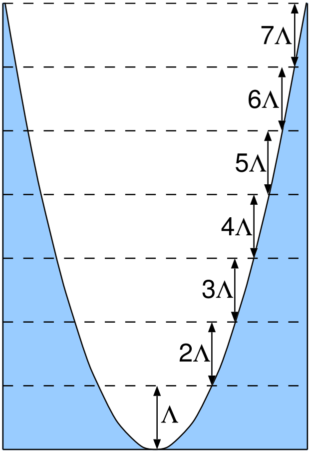
$$h(x) = \Lambda \left(\frac{x}{\sqrt{2\lambda_o f}} \right)^2$$

when $h(x) = 100\Lambda \sim 1000\mu\text{m}$

$$x = 10\sqrt{2\lambda_o f} \sim 100\mu\text{m}$$

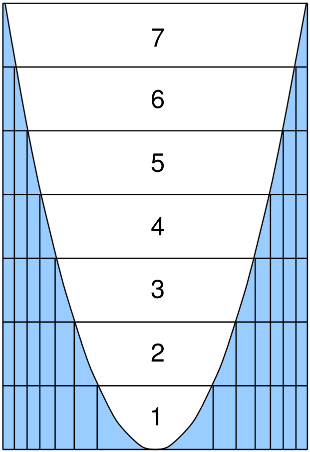
aspect ratio too large for a stable structure and absorption would be too large!

How to make a Fresnel lens



Mark off the longitudinal zones (of thickness Λ) where the waves inside and outside the material are in phase.

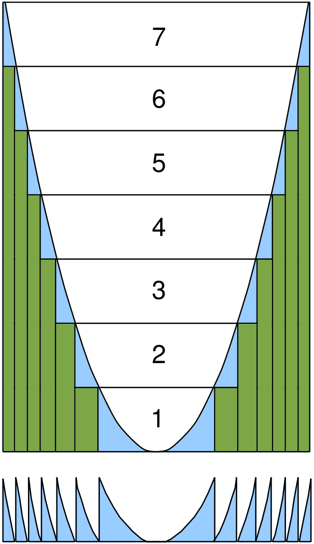
How to make a Fresnel lens



Mark off the longitudinal zones (of thickness Λ) where the waves inside and outside the material are in phase.

Each block of thickness Λ serves no purpose for refraction but only attenuates the wave.

How to make a Fresnel lens

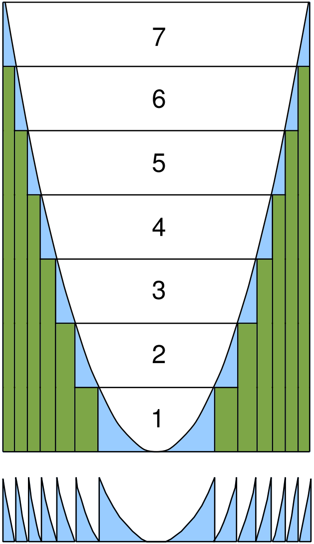


Mark off the longitudinal zones (of thickness Λ) where the waves inside and outside the material are in phase.

Each block of thickness Λ serves no purpose for refraction but only attenuates the wave.

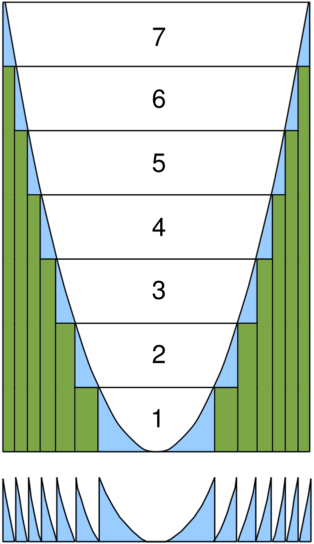
This material can be removed and the remaining material collapsed to produce a Fresnel lens which has the same optical properties as the parabolic lens as long as $f \gg N\Lambda$ where N is the number of zones.

Fresnel lens dimensions



The outermost zones become very small and thus limit the overall aperture of the zone plate. The dimensions of outermost zone, N can be calculated by first defining a scaled height and lateral dimension

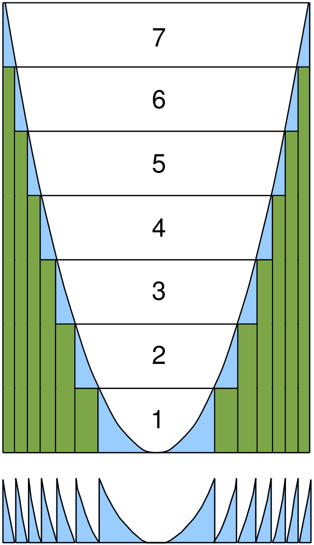
Fresnel lens dimensions



The outermost zones become very small and thus limit the overall aperture of the zone plate. The dimensions of outermost zone, N can be calculated by first defining a scaled height and lateral dimension

$$\nu = \frac{h(x)}{\Lambda}$$

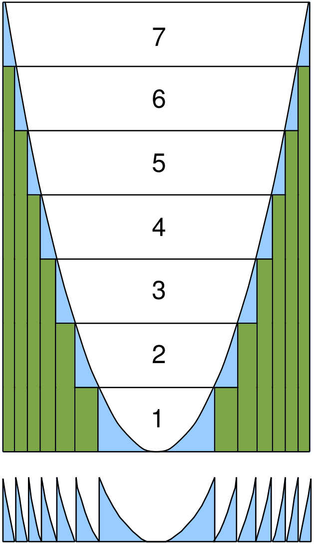
Fresnel lens dimensions



The outermost zones become very small and thus limit the overall aperture of the zone plate. The dimensions of outermost zone, N can be calculated by first defining a scaled height and lateral dimension

$$\nu = \frac{h(x)}{\Lambda} \qquad \xi = \frac{x}{\sqrt{2\lambda_o f}}$$

Fresnel lens dimensions

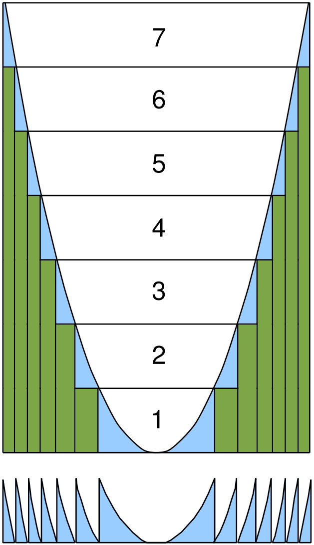


The outermost zones become very small and thus limit the overall aperture of the zone plate. The dimensions of outermost zone, N can be calculated by first defining a scaled height and lateral dimension

$$\nu = \frac{h(x)}{\Lambda} \qquad \xi = \frac{x}{\sqrt{2\lambda_o f}}$$

Since $\nu = \xi^2$, the position of the N^{th} zone is $\xi_N = \sqrt{N}$ and the scaled width of the N^{th} (outermost) zone is

Fresnel lens dimensions



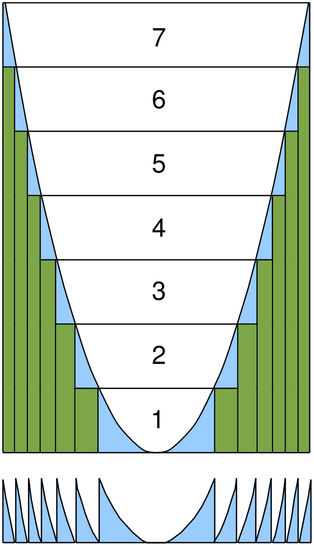
The outermost zones become very small and thus limit the overall aperture of the zone plate. The dimensions of outermost zone, N can be calculated by first defining a scaled height and lateral dimension

$$\nu = \frac{h(x)}{\Lambda} \qquad \xi = \frac{x}{\sqrt{2\lambda_o f}}$$

Since $\nu = \xi^2$, the position of the N^{th} zone is $\xi_N = \sqrt{N}$ and the scaled width of the N^{th} (outermost) zone is

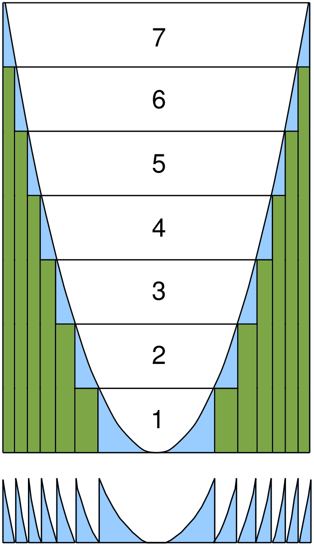
$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$

Fresnel lens dimensions



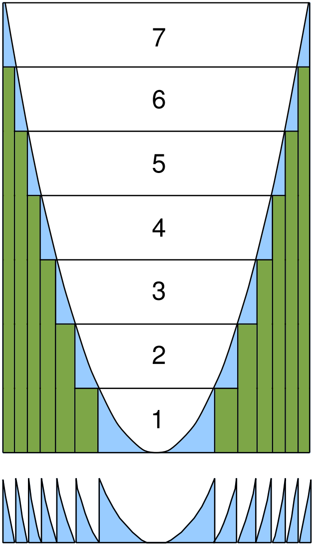
$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$

Fresnel lens dimensions



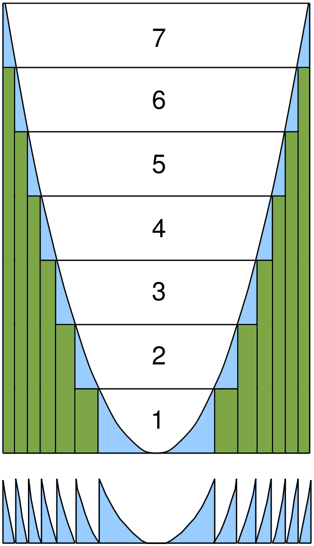
$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$
$$= \sqrt{N}\left(1 - \sqrt{1 - \frac{1}{N}}\right)$$

Fresnel lens dimensions



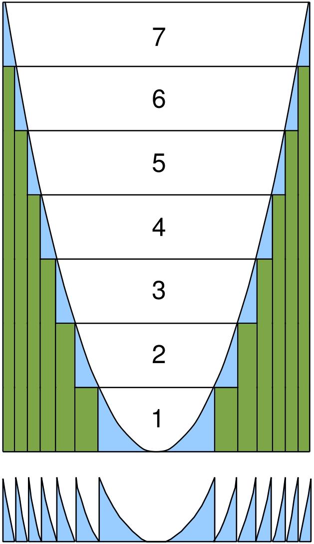
$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$
$$= \sqrt{N}\left(1 - \sqrt{1 - \frac{1}{N}}\right)$$
$$\approx \sqrt{N}\left(1 - \left[1 - \frac{1}{2N}\right]\right)$$

Fresnel lens dimensions



$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$
$$= \sqrt{N}\left(1 - \sqrt{1 - \frac{1}{N}}\right)$$
$$\approx \sqrt{N}\left(1 - \left[1 - \frac{1}{2N}\right]\right)$$
$$\Delta\xi_N \approx \frac{1}{2\sqrt{N}}$$

Fresnel lens dimensions



$$\Delta\xi_N = \xi_N - \xi_{N-1} = \sqrt{N} - \sqrt{N-1}$$

$$= \sqrt{N}\left(1 - \sqrt{1 - \frac{1}{N}}\right)$$

$$\approx \sqrt{N}\left(1 - \left[1 - \frac{1}{2N}\right]\right)$$

$$\Delta\xi_N \approx \frac{1}{2\sqrt{N}}$$

The diameter of the entire lens is thus

$$2\xi_N = 2\sqrt{N} = \frac{1}{\Delta\xi_N}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

$$d_N = 2\xi_N$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta \xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

$$d_N = 2\xi_N = \frac{\sqrt{2\lambda_o f}}{\Delta \xi_N}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

$$d_N = 2\xi_N = \frac{\sqrt{2\lambda_o f}}{\Delta\xi_N} = 2\sqrt{N}\sqrt{2\lambda_o f} = \sqrt{2N\lambda_o f}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

$$d_N = 2\xi_N = \frac{\sqrt{2\lambda_o f}}{\Delta\xi_N} = 2\sqrt{N}\sqrt{2\lambda_o f} = \sqrt{2N\lambda_o f}$$

If we take

$$\lambda_o = 1\text{Å} = 1 \times 10^{-10}\text{m}$$
$$f = 50\text{cm} = 0.5\text{m}$$
$$N = 100$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N \sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

$$d_N = 2\xi_N = \frac{\sqrt{2\lambda_o f}}{\Delta\xi_N} = 2\sqrt{N}\sqrt{2\lambda_o f} = \sqrt{2N\lambda_o f}$$

If we take

$$\lambda_o = 1\text{Å} = 1 \times 10^{-10}\text{m}$$
$$f = 50\text{cm} = 0.5\text{m}$$
$$N = 100$$

$$\Delta x_N = 5 \times 10^{-7}\text{m} = 500\text{nm}$$

Fresnel lens example

In terms of the unscaled variables

$$\Delta x_N = \Delta\xi_N\sqrt{2\lambda_o f} = \sqrt{\frac{\lambda_o f}{2N}}$$

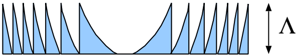
$$d_N = 2\xi_N = \frac{\sqrt{2\lambda_o f}}{\Delta\xi_N} = 2\sqrt{N}\sqrt{2\lambda_o f} = \sqrt{2N\lambda_o f}$$

If we take

$$\lambda_o = 1\text{Å} = 1\times10^{-10}\text{m}$$
$$f = 50\text{cm} = 0.5\text{m}$$
$$N = 100$$

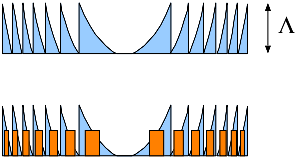
$$\Delta x_N = 5\times10^{-7}\text{m} = 500\text{nm} \qquad d_N = 2\times10^{-4}\text{m} = 100\mu\text{m}$$

Making a Fresnel zone plate



The specific shape required for a zone plate is difficult to fabricate, consequently, it is convenient to approximate the nearly triangular zones with a rectangular profile.

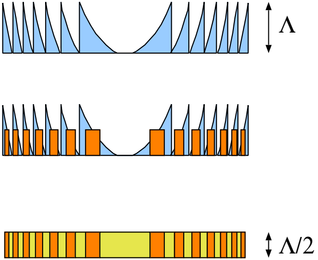
Making a Fresnel zone plate



The specific shape required for a zone plate is difficult to fabricate, consequently, it is convenient to approximate the nearly triangular zones with a rectangular profile.

In practice, since the outermost zones are very small, zone plates are generally fabricated as alternating zones (rings for 2D) of materials with a large Z-contrast, such as Au/Si or W/C.

Making a Fresnel zone plate



The specific shape required for a zone plate is difficult to fabricate, consequently, it is convenient to approximate the nearly triangular zones with a rectangular profile.

In practice, since the outermost zones are very small, zone plates are generally fabricated as alternating zones (rings for 2D) of materials with a large Z-contrast, such as Au/Si or W/C.

This kind of zone plate is not as efficient as a true Fresnel lens would be in the x-ray regime. Nevertheless, efficiencies up to 35% have been achieved.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

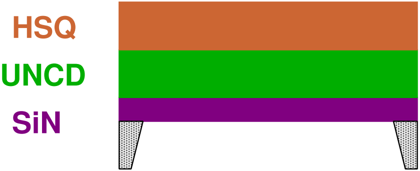
Start with Ultra nano crystalline diamond (UNCD) films on SiN.

M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ).



M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

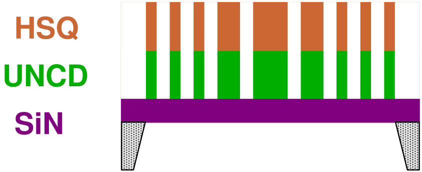
Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ). Pattern and develop the HSQ layer.

M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ). Pattern and develop the HSQ layer. Reactive ion etch the UNCD to the substrate.

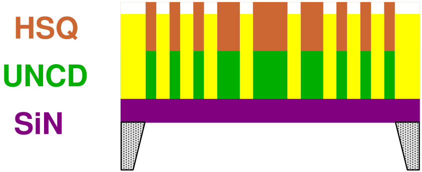


M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ). Pattern and develop the HSQ layer. Reactive ion etch the UNCD to the substrate. Plate with gold to make final zone plate.



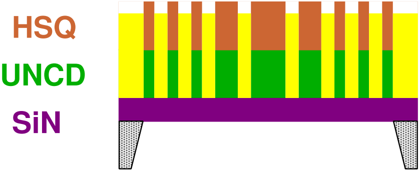
M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

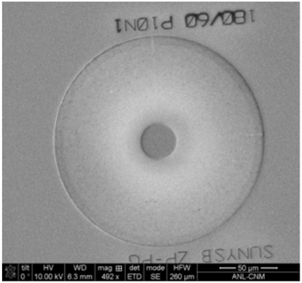
Zone plate fabrication

Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ). Pattern and develop the HSQ layer. Reactive ion etch the UNCD to the substrate. Plate with gold to make final zone plate.

The whole 150nm diameter zone plate



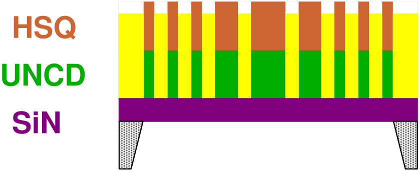


M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Zone plate fabrication

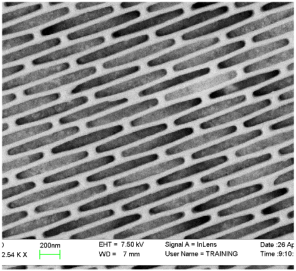
Making high aspect ratio zone plates is challenging but a new process has been developed to make plates with an aspect ratio as high as 25.

Start with Ultra nano crystalline diamond (UNCD) films on SiN. Coat with hydrogen silsesquioxane (HSQ). Pattern and develop the HSQ layer. Reactive ion etch the UNCD to the substrate. Plate with gold to make final zone plate.



The whole 150nm diameter zone plate

Detail view of outer zones



M. Wojick et al., "High Aspect Ratio Zone Plate Fabrication Using a Bilayer Mold", *EIBPN 2011*.

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

$$\frac{\mu_{10keV}}{\mu_{5kev}} = \frac{1/10^3}{1/5^3}$$

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

$$\frac{\mu_{10keV}}{\mu_{5kev}} = \frac{1/10^3}{1/5^3}$$

$$\mu_{10keV} = \mu_{5keV}\left(\frac{5}{10}\right)^3$$

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

$$\frac{\mu_{10keV}}{\mu_{5kev}} = \frac{1/10^3}{1/5^3}$$

$$\mu_{10keV} = \mu_{5keV}\left(\frac{5}{10}\right)^3$$

$$= 1698.3\,\text{cm}^{-1}\left(\frac{1}{8}\right)$$

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

$$\frac{\mu_{10keV}}{\mu_{5kev}} = \frac{1/10^3}{1/5^3}$$

$$\mu_{10keV} = \mu_{5keV}\left(\frac{5}{10}\right)^3$$

$$= 1698.3\,\text{cm}^{-1}\left(\frac{1}{8}\right) = 212\,\text{cm}^{-1}$$

Homework 02 - Problem 1

Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate

(a) The absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1}.

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

(a) We are given the energy dependence of the absorption coefficient and its value at 5 keV.

(b) The calculation does not take into account the Cu K absorption edge at 8.98 keV.

$$\frac{\mu_{10keV}}{\mu_{5kev}} = \frac{1/10^3}{1/5^3}$$

$$\mu_{10keV} = \mu_{5keV}\left(\frac{5}{10}\right)^3$$

$$= 1698.3\,\text{cm}^{-1}\left(\frac{1}{8}\right) = 212\,\text{cm}^{-1}$$

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10$ nA is measured, what is the photon flux entering the ionization chamber?

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10$ nA is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10$ nA is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

$$\frac{dN}{dt} = [f(E)\,\Phi]\left[\frac{E}{W}\right]$$

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10\,\text{nA}$ is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

$$\frac{dN}{dt} = [f(E)\,\Phi]\left[\frac{E}{W}\right]$$

where $f(E)$ is the fraction of the beam absorbed, Φ is the total flux incident on the ion chamber, E is the energy of a single photon, and W is the energy required to produce a free electron in the gas mixture.

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10$ nA is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

$$\frac{dN}{dt} = [f(E)\,\Phi]\left[\frac{E}{W}\right]$$

where $f(E)$ is the fraction of the beam absorbed, Φ is the total flux incident on the ion chamber, E is the energy of a single photon, and W is the energy required to produce a free electron in the gas mixture. The fraction of photons absorbed is given by

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i = 10$ nA is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

$$\frac{dN}{dt} = [f(E)\,\Phi]\left[\frac{E}{W}\right]$$

where $f(E)$ is the fraction of the beam absorbed, Φ is the total flux incident on the ion chamber, E is the energy of a single photon, and W is the energy required to produce a free electron in the gas mixture. The fraction of photons absorbed is given by

$$f(E) = \frac{I_0 - I(L)}{I_0}$$

Homework 02 - Problem 2

A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of $i =$10 nA is measured, what is the photon flux entering the ionization chamber?

The number of free electrons per second generated in the ion chamber by the beam is given by

$$\frac{dN}{dt} = [f(E)\,\Phi]\left[\frac{E}{W}\right]$$

where $f(E)$ is the fraction of the beam absorbed, Φ is the total flux incident on the ion chamber, E is the energy of a single photon, and W is the energy required to produce a free electron in the gas mixture. The fraction of photons absorbed is given by

$$f(E) = \frac{I_0 - I(L)}{I_0} = 1 - e^{-\mu L}$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber.

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber.

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

$$\mu_{He} = 2.0 \times 10^{-6}\,\text{cm}^{-1}$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu_{He} = 2.0 \times 10^{-6}\,\text{cm}^{-1}$$

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

$$\mu_{N_2} = 2.29 \times 10^{-3}$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

$$\mu_{He} = 2.0 \times 10^{-6}\,\text{cm}^{-1}$$

$$\mu_{N_2} = 2.29 \times 10^{-3}$$

$$\mu = 0.8\mu_{He} + 0.2\mu_{N_2}$$

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

$$\mu_{He} = 2.0 \times 10^{-6}\,\text{cm}^{-1}$$

$$\mu_{N_2} = 2.29 \times 10^{-3}$$

$$\mu = 0.8\mu_{He} + 0.2\mu_{N_2} = 0.8 \cdot 2.0 \times 10^{-6} + 0.2 \cdot 2.29 \times 10^{-3}$$

Homework 02 - Problem 2 (cont.)

The total absorption coefficient μ is a weighted sum of the absorption of the substance in the ion chamber. Where the quantity μ_i can be computed from the absorption cross section of each component ($\sigma_{a,i}$), its mass density ($\rho_{m,i}$), molar mass (M_i), and Avogadro's number (N_A).

$$\mu = \sum_{i=1}^{N} x_i \mu_i$$

$$\mu_i = \left(\frac{\rho_{m,i} N_A}{M_i} \right) \sigma_{a,i}$$

These values can be computed or looked up in the orange book or on the MuCal online calculator for the energy desired. For $E = 12\,\text{keV}$, the *photoelectric* cross-section is

$$\mu_{He} = 2.0 \times 10^{-6}\,\text{cm}^{-1} \qquad \mu_{N_2} = 2.29 \times 10^{-3}$$

$$\begin{aligned}\mu &= 0.8\mu_{He} + 0.2\mu_{N_2} = 0.8 \cdot 2.0 \times 10^{-6} + 0.2 \cdot 2.29 \times 10^{-3} \\ &= 4.60 \times 10^{-4}\,\text{cm}^{-1}\end{aligned}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$
$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$

$$= 0.0136 = 1.36\%$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\mathrm{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$

$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$

$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$

$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$

$$W = 0.8 \cdot 41 + 0.2 \cdot 36$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$
$$W = 0.8 \cdot 41 + 0.2 \cdot 36 = 40\,\text{eV}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$
$$W = 0.8 \cdot 41 + 0.2 \cdot 36 = 40\,\text{eV}$$

Putting it all together

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

The number of electrons per second can be computed directly from the measured current

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$
$$W = 0.8 \cdot 41 + 0.2 \cdot 36 = 40\,\text{eV}$$

Putting it all together

$$\Phi = \frac{dN}{dt}\frac{W}{f(E)E}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$
$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10\times 10^{-9}}{1.602\times 10^{-19}}$$
$$= 6.24\times 10^{10}\,\text{s}^{-1}$$

The number of electrons per second can be computed directly from the measured current

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$
$$W = 0.8\cdot 41 + 0.2\cdot 36 = 40\,\text{eV}$$

Putting it all together

$$\Phi = \frac{dN}{dt}\frac{W}{f(E)E} = \frac{(6.24\times^{10}\ \text{s}^{-1})(40\,\text{eV})}{(0.0136)(12\times 10^3\,\text{eV/photon})}$$

Homework 02 - Problem 2 (cont.)

Now we use this to calculate the fraction of photons absorbed in the chamber

$$\mu = 4.60 \times 10^{-4}\,\text{cm}^{-1}$$

$$f(E) = 1 - e^{-\mu L} = 1 - e^{-4.60\times^{-4}\cdot 30}$$
$$= 0.0136 = 1.36\%$$

$$\frac{dN}{dt} = \frac{i}{e} = \frac{10 \times 10^{-9}}{1.602 \times 10^{-19}}$$
$$= 6.24 \times 10^{10}\,\text{s}^{-1}$$

The number of electrons per second can be computed directly from the measured current

Finally, we look up in the orange book the energy required to make a free electron by inoization for each gas and take a weighted average

$$W_{He} = 41\,\text{eV} \qquad W_{N_2} = 36\,\text{eV}$$
$$W = 0.8 \cdot 41 + 0.2 \cdot 36 = 40\,\text{eV}$$

Putting it all together

$$\Phi = \frac{dN}{dt}\frac{W}{f(E)E} = \frac{(6.24 \times^{10}\ \text{s}^{-1})(40\,\text{eV})}{(0.0136)(12 \times 10^3\,\text{eV/photon})} = 1.53 \times 10^{10}\,\text{photon/s}$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$

$$e^{-\mu L} = [1 - f(E)]$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$
$$e^{-\mu L} = [1 - f(E)]$$
$$-\mu L = \ln[1 - f(E)]$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$
$$e^{-\mu L} = [1 - f(E)]$$
$$-\mu L = \ln[1 - f(E)]$$
$$\mu = \frac{-\ln[1 - f(E)]}{L}$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$

$$e^{-\mu L} = [1 - f(E)]$$

$$-\mu L = \ln[1 - f(E)]$$

$$\mu = \frac{-\ln[1 - f(E)]}{L}$$

$$= \frac{-\ln[1 - 0.6]}{5\,\text{cm}}$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

$$f(E) = 1 - e^{-\mu L}$$

$$e^{-\mu L} = [1 - f(E)]$$

$$-\mu L = \ln[1 - f(E)]$$

$$\mu = \frac{-\ln[1 - f(E)]}{L}$$

$$= \frac{-\ln[1 - 0.6]}{5\,\text{cm}} = 0.183\,\text{cm}^{-1}$$

Homework 02 - Problem 3

A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

The energy of the arsenic fluorescence line can be obtained from MuCal or from Hephaestus and is 10.54 keV. We would like to have at least 60% absorption in the 5 cm chamber. This can give us the desired value of μ.

This is the minimum value of the absorption that we require.

$$f(E) = 1 - e^{-\mu L}$$

$$e^{-\mu L} = [1 - f(E)]$$

$$-\mu L = \ln[1 - f(E)]$$

$$\mu = \frac{-\ln[1 - f(E)]}{L}$$

$$= \frac{-\ln[1 - 0.6]}{5\,\text{cm}} = 0.183\,\text{cm}^{-1}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\mathrm{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$
$\mu_{Ar} = 0.098\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1}$ $\mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$ $\mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1}$ $\mu_{Kr} = 0.17\,\text{cm}^{-1}$ $\mu_{Xe} = 0.89\,\text{cm}^{-1}$ $\mu_{Rn} = 1.3\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Xe} = 1 - e^{-(0.89)(5)}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1}$ $\quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$ $\quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1}$ $\quad \mu_{Kr} = 0.17\,\text{cm}^{-1}$ $\quad \mu_{Xe} = 0.89\,\text{cm}^{-1}$ $\quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1}$ $\mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$ $\mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1}$ $\mu_{Kr} = 0.17\,\text{cm}^{-1}$ $\mu_{Xe} = 0.89\,\text{cm}^{-1}$ $\mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1} \quad \mu_{Rn} = 0.99\,\text{cm}^{-1}$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1} \quad \mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1} \quad \mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)} = 1 - 0.32 = 68\%$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1}$ $\mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$ $\mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1}$ $\mu_{Kr} = 0.17\,\text{cm}^{-1}$ $\mu_{Xe} = 0.89\,\text{cm}^{-1}$ $\mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1}$ $\mu_{Kr} = 0.23\,\text{cm}^{-1}$ $\mu_{Xe} = 0.17\,\text{cm}^{-1}$ $\mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)} = 1 - 0.32 = 68\%$$
$$f(E)_{Xe} = 1 - e^{-(0.17)(5)}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1} \quad \mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)} = 1 - 0.32 = 68\%$$
$$f(E)_{Xe} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1}$ $\mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1}$ $\mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1}$ $\mu_{Kr} = 0.17\,\text{cm}^{-1}$ $\mu_{Xe} = 0.89\,\text{cm}^{-1}$ $\mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1}$ $\mu_{Kr} = 0.23\,\text{cm}^{-1}$ $\mu_{Xe} = 0.17\,\text{cm}^{-1}$ $\mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)} = 1 - 0.32 = 68\%$$

$$f(E)_{Xe} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$

$$f(E)_{Rn} = 1 - e^{-(0.99)(5)}$$

Homework 02 - Problem 3 (cont.)

Looking at tabulated values of the absorption coefficient for various gases at this energy (from MuCal, *total* cross-section):

$\mu_{He} = 4.2 \times 10^{-5}\,\text{cm}^{-1} \quad \mu_{N_2} = 3.9 \times 10^{-3}\,\text{cm}^{-1} \quad \mu_{Ne} = 8.8 \times 10^{-3}\,\text{cm}^{-1}$

$\mu_{Ar} = 0.098\,\text{cm}^{-1} \quad \mu_{Kr} = 0.17\,\text{cm}^{-1} \quad \mu_{Xe} = 0.89\,\text{cm}^{-1} \quad \mu_{Rn} = 1.3\,\text{cm}^{-1}$

Thus for the most likely candidates we have

$$f(E)_{Kr} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Xe} = 1 - e^{-(0.89)(5)} = 1 - 0.01 = 99\%$$

For the Ru K-edge at 19.28 keV, we have

$\mu_{Ar} = 0.017\,\text{cm}^{-1} \quad \mu_{Kr} = 0.23\,\text{cm}^{-1} \quad \mu_{Xe} = 0.17\,\text{cm}^{-1} \quad \mu_{Rn} = 0.99\,\text{cm}^{-1}$

$$f(E)_{Kr} = 1 - e^{-(0.23)(5)} = 1 - 0.32 = 68\%$$
$$f(E)_{Xe} = 1 - e^{-(0.17)(5)} = 1 - 0.43 = 57\%$$
$$f(E)_{Rn} = 1 - e^{-(0.99)(5)} = 1 - 0.01 = 99\%$$

Homework 02 - Problem 4

Calculate the characteristic angle of reflection of 10keV and 30keV x-rays for:

(a) A slab of glass (SiO_2)

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2mm high, what length of mirror is required to reflect the entire beam for each material?

Homework 02 - Problem 4

Calculate the characteristic angle of reflection of 10keV and 30keV x-rays for:

(a) A slab of glass (SiO_2)

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2mm high, what length of mirror is required to reflect the entire beam for each material?

The critical angle is related to the index of refraction,

Homework 02 - Problem 4

Calculate the characteristic angle of reflection of 10keV and 30keV x-rays for:

(a) A slab of glass (SiO_2)

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2mm high, what length of mirror is required to reflect the entire beam for each material?

The critical angle is related to the index of refraction, with $r_0 = 2.82 \times 10^{-5}$Å

$$\alpha_c = \sqrt{2\delta}, \quad \delta = \frac{2\pi\rho r_0}{k^2}$$

Homework 02 - Problem 4

Calculate the characteristic angle of reflection of 10keV and 30keV x-rays for:

(a) A slab of glass (SiO_2)

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2mm high, what length of mirror is required to reflect the entire beam for each material?

The critical angle is related to the index of refraction, with $r_0 = 2.82 \times 10^{-5}$Å

$$\alpha_c = \sqrt{2\delta}, \quad \delta = \frac{2\pi\rho r_0}{k^2}$$

the electron density ρ can be computed using the mass density, ρ_m

Homework 02 - Problem 4

Calculate the characteristic angle of reflection of 10keV and 30keV x-rays for:

(a) A slab of glass (SiO_2)

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2mm high, what length of mirror is required to reflect the entire beam for each material?

The critical angle is related to the index of refraction, with $r_0 = 2.82 \times 10^{-5}$Å

$$\alpha_c = \sqrt{2\delta}, \quad \delta = \frac{2\pi\rho r_0}{k^2}$$

the electron density ρ can be computed using the mass density, ρ_m

$$\rho[e^-/\text{Å}^3] = \frac{\rho_m[g/\text{cm}^3] \cdot N_A[\text{atom/mol}] \cdot Z[e^-/\text{atom}]}{M[\text{g/mol}] \cdot (10^8[\text{Å/cm}])^3}$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc}$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])}$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51E[\text{keV}]$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51 E[\text{keV}]$$

now the expression for the critical angle becomes

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51 E[\text{keV}]$$

now the expression for the critical angle becomes

$$\alpha_c = \sqrt{4\pi(2.82 \times 10^{-5}[\text{Å}])}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{k\left[\text{Å}^{-1}\right]}$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51E[\text{keV}]$$

now the expression for the critical angle becomes

$$\alpha_c = \sqrt{4\pi(2.82 \times 10^{-5}[\text{Å}])}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{k\left[\text{Å}^{-1}\right]} = 3.71 \times 10^{-2}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{E[\text{keV}]}$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51 E[\text{keV}]$$

now the expression for the critical angle becomes

$$\alpha_c = \sqrt{4\pi(2.82 \times 10^{-5}[\text{Å}])}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{k\left[\text{Å}^{-1}\right]} = 3.71 \times 10^{-2}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{E[\text{keV}]}$$

for the two energies specified (10 keV and 30 keV), we have

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51E[\text{keV}]$$

now the expression for the critical angle becomes

$$\alpha_c = \sqrt{4\pi(2.82 \times 10^{-5}[\text{Å}])}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{k\left[\text{Å}^{-1}\right]} = 3.71 \times 10^{-2}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{E[\text{keV}]}$$

for the two energies specified (10 keV and 30 keV), we have

$$\alpha_{c10} = 3.71 \times 10^{-3}\sqrt{\rho},$$

Homework 02 - Problem 4 (cont.)

The wave number for the radiation is given by

$$k\left[\text{Å}^{-1}\right] = \frac{2\pi E}{hc} = \frac{2\pi E[\text{keV}] \times 10^3}{(4.135 \times 10^{-15}[\text{eV}\cdot\text{s}])(3 \times 10^{18}[\text{Å/s}])} = 0.51 E[\text{keV}]$$

now the expression for the critical angle becomes

$$\alpha_c = \sqrt{4\pi(2.82 \times 10^{-5}[\text{Å}])}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{k\left[\text{Å}^{-1}\right]} = 3.71 \times 10^{-2}\frac{\sqrt{\rho\left[e^-/\text{Å}^3\right]}}{E[\text{keV}]}$$

for the two energies specified (10 keV and 30 keV), we have

$$\alpha_{c10} = 3.71 \times 10^{-3}\sqrt{\rho}, \qquad \alpha_{c30} = 1.20 \times 10^{-3}\sqrt{\rho}$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$\rho = 0.662\text{Å}^{-3}$,

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ,$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \ \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$\rho = 1.99\text{Å}^{-3},$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ,$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \;\; \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \ \ \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \ \ \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$\rho = 0.662\text{Å}^{-3}$, $\quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ$, $\alpha_{c30} = 1.01\text{mrad} = 0.06^\circ$,

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$\rho = 1.99\text{Å}^{-3}$, $\quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ$, $\alpha_{c30} = 1.75\text{mrad} = 0.10^\circ$,

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$\rho = 5.16\text{Å}^{-3}$,

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$\rho = 0.662\text{Å}^{-3}$, $\alpha_{c10} = 3.02\text{mrad} = 0.17^\circ$, $\alpha_{c30} = 1.01\text{mrad} = 0.06^\circ$,

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$\rho = 1.99\text{Å}^{-3}$, $\alpha_{c10} = 5.25\text{mrad} = 0.30^\circ$, $\alpha_{c30} = 1.75\text{mrad} = 0.10^\circ$,

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$\rho = 5.16\text{Å}^{-3}$, $\alpha_{c10} = 8.44\text{mrad} = 0.48^\circ$,

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \;\; \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$$\rho = 5.16\text{Å}^{-3}, \quad \alpha_{c10} = 8.44\text{mrad} = 0.48^\circ, \;\; \alpha_{c30} = 2.81\text{mrad} = 0.16^\circ,$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \;\; \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$$\rho = 5.16\text{Å}^{-3}, \quad \alpha_{c10} = 8.44\text{mrad} = 0.48^\circ, \;\; \alpha_{c30} = 2.81\text{mrad} = 0.16^\circ,$$

(d) The length of the the mirror required to capture the entire 2 mm high beam is given by

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \ \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \ \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$$\rho = 5.16\text{Å}^{-3}, \quad \alpha_{c10} = 8.44\text{mrad} = 0.48^\circ, \ \alpha_{c30} = 2.81\text{mrad} = 0.16^\circ,$$

(d) The length of the the mirror required to capture the entire 2 mm high beam is given by

$$L = \frac{2\text{mm}}{\alpha_c}$$

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \;\; \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$$\rho = 5.16\text{Å}^{-3}, \quad \alpha_{c10} = 8.44\text{mrad} = 0.48^\circ, \;\; \alpha_{c30} = 2.81\text{mrad} = 0.16^\circ,$$

(d) The length of the the mirror required to capture the entire 2 mm high beam is given by

$$L = \frac{2\text{mm}}{\alpha_c}$$

for the 6 cases in (a-c) we have

Homework 02 - Problem 4 (cont.)

(a) for SiO_2, $\rho_m = 2.2$ g/cm^2, $M = 60$ g/mol, $Z = 30$

$$\rho = 0.662\text{Å}^{-3}, \quad \alpha_{c10} = 3.02\text{mrad} = 0.17^\circ, \;\; \alpha_{c30} = 1.01\text{mrad} = 0.06^\circ,$$

(b) for Cr, $\rho_m = 7.19$ g/cm^2, $M = 52$ g/mol, $Z = 24$

$$\rho = 1.99\text{Å}^{-3}, \quad \alpha_{c10} = 5.25\text{mrad} = 0.30^\circ, \;\; \alpha_{c30} = 1.75\text{mrad} = 0.10^\circ,$$

(c) for Pt, $\rho_m = 21.4$ g/cm^2, $M = 195$ g/mol, $Z = 78$

$$\rho = 5.16\text{Å}^{-3}, \quad \alpha_{c10} = 8.44\text{mrad} = 0.48^\circ, \;\; \alpha_{c30} = 2.81\text{mrad} = 0.16^\circ,$$

(d) The length of the the mirror required to capture the entire 2 mm high beam is given by

$$L = \frac{2\text{mm}}{\alpha_c}$$

for the 6 cases in (a-c) we have

	10 keV	30 keV
SiO_2	0.67 m	2.00 m
Cr	0.38 m	1.14 m
Pt	0.25 m	0.72 m

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1},$$

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1}, \qquad \mu_{Ge} = 168\text{cm}^{-1},$$

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1}, \qquad \mu_{Ge} = 168\text{cm}^{-1},$$

the percentage of photons absorbed is given by

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1}, \qquad \mu_{Ge} = 168\text{cm}^{-1},$$

the percentage of photons absorbed is given by

$$f(E) = \frac{I_0 - I(L)}{I_0} = 1 - e^{-\mu L}$$

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1}, \qquad \mu_{Ge} = 168\text{cm}^{-1},$$

the percentage of photons absorbed is given by

$$f(E) = \frac{I_0 - I(L)}{I_0} = 1 - e^{-\mu L}$$

$$f_{Si}(E) = 1 - e^{-(7.5)(0.1)} = 0.53 = 53\%$$

Homework 02 - Problem 5

Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

The Ag K_α fluorescence line is at 22.2 keV and the absorption coefficients for Si and Ge at that energy, are

$$\mu_{Si} = 7.5\text{cm}^{-1}, \qquad \mu_{Ge} = 168\text{cm}^{-1},$$

the percentage of photons absorbed is given by

$$f(E) = \frac{I_0 - I(L)}{I_0} = 1 - e^{-\mu L}$$

$$f_{Si}(E) = 1 - e^{-(7.5)(0.1)} = 0.53 = 53\%$$

$$f_{Ge}(E) = 1 - e^{-(168)(0.1)} = 0.99 = 99\%,$$

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

$$N_{Si} = \frac{f_{Si}(E)}{W_{Si}} E = \frac{0.53}{3.7} 2.22 \times 10^4 = 3175,$$

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

$$N_{Si} = \frac{f_{Si}(E)}{W_{Si}} E = \frac{0.53}{3.7} 2.22 \times 10^4 = 3175,$$

$$N_{Ge} = \frac{f_{Ge}(E)}{W_{Ge}} E = \frac{0.99}{3.0} 2.22 \times 10^4 = 7393$$

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

$$N_{Si} = \frac{f_{Si}(E)}{W_{Si}} E = \frac{0.53}{3.7} 2.22 \times 10^4 = 3175,$$

$$N_{Ge} = \frac{f_{Ge}(E)}{W_{Ge}} E = \frac{0.99}{3.0} 2.22 \times 10^4 = 7393$$

we get the charge pulse by multiplying by the charge per electron

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

$$N_{Si} = \frac{f_{Si}(E)}{W_{Si}} E = \frac{0.53}{3.7} 2.22 \times 10^4 = 3175,$$

$$N_{Ge} = \frac{f_{Ge}(E)}{W_{Ge}} E = \frac{0.99}{3.0} 2.22 \times 10^4 = 7393$$

we get the charge pulse by multiplying by the charge per electron

$$\delta q_{Si} = 5.1 \times 10^{-16}\text{C},$$

Homework 02 - Problem 5 (cont.)

The energy required to create an electron-hole pair (W) is 3.7 eV for Si and 3.0 eV for Ge, so the number of electrons produced is

$$N = \frac{f(E)}{W} E[\text{ev}]$$

$$N_{Si} = \frac{f_{Si}(E)}{W_{Si}} E = \frac{0.53}{3.7} 2.22 \times 10^4 = 3175,$$

$$N_{Ge} = \frac{f_{Ge}(E)}{W_{Ge}} E = \frac{0.99}{3.0} 2.22 \times 10^4 = 7393$$

we get the charge pulse by multiplying by the charge per electron

$$\delta q_{Si} = 5.1 \times 10^{-16}\text{C}, \qquad \delta q_{Ge} = 1.2 \times 10^{-15}\text{C}$$