5. The wavelength of the red light from a helium-neon laser is 633 nm in the air, but 474 nm in the jellylike fluid inside your eyeball, called vitreous humour. Calculate the index of refraction of the vitreous humour and the speed and frequency of the light passing through it.
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\[ n = 1.0 \quad \rightarrow \quad n_{\text{medium}} \]

When light travels through a medium its speed is reduced by a factor of \( \frac{1}{n} \) where \( n \) is the refractive index.

\[ v = \frac{c}{n_{\text{medium}}} \]

Where \( v \) is the speed of light in the medium, and \( c \) is the speed of light in vacuum (and approximately the speed of light in air).

5. The wavelength of the red light from a helium-neon laser is 633 nm in the air, but 474 nm in the jellylike fluid inside your eyeball, called vitreous humour. Calculate the index of refraction of the vitreous humour and the speed and frequency of the light passing through it.

\[ n = 1.0 \quad \rightarrow \quad n_{\text{medium}} \]

But the frequency of the light is unchanged, so the wavelength is also reduced by a factor of \( \frac{1}{n} \).

\[ \lambda_{\text{medium}} = \frac{\lambda_{\text{vacuum}}}{n_{\text{medium}}} \]
5. The wavelength of the red light from a helium-neon laser is 633 nm in the air, but 474 nm in the jellylike fluid inside your eyeball, called vitreous humour. Calculate the index of refraction of the vitreous humour and the speed and frequency of the light passing through it.

\[ n = 1.0 \quad \text{and} \quad n_{medium} \]

\[ \lambda_{medium} = \lambda_{vacuum} / n_{medium} \]

\[ n_{medium} = \lambda_{vacuum} / \lambda_{medium} = 633 / 474 \]

\[ = 1.335 \]

Now we have \( n_{medium} \) we can calculate the speed \( v \).

\[ v = c / n_{medium} = 3.00 \times 10^8 / 1.335 \]

\[ = 2.25 \times 10^8 \text{ m/s} \]
5. The wavelength of the red light from a helium-neon laser is 633 nm in the air, but 474 nm in the jellylike fluid inside your eyeball, called vitreous humour. Calculate the index of refraction of the vitreous humour and the speed and frequency of the light passing through it.

\[ n = 1.0 \quad \text{n}_{\text{medium}} \]

To calculate frequency we use

\[ c = f\lambda \]

\[ f = \frac{c}{\lambda} = \frac{3 \times 10^8}{633 \times 10^{-9}} \quad (1 \text{ nm} = 10^{-9} \text{ m}) \]

\[ = 4.74 \times 10^{14} \text{ Hz} \]

6. A light ray is incident on the end of a straight optical fibre at angle \( \theta_1 \) and enters the fibre at angle \( \theta_2 \) (see figure). If refractive index of the fibre is 1.2, what is the maximum value of \( \theta_1 \) such that the light remains within the fibre.
6. A light ray is incident on the end of a straight optical fibre at angle \( \theta_1 \) and enters the fibre at angle \( \theta_2 \) (see figure). If refractive index of the fibre is 1.2, what is the maximum value of \( \theta_1 \) such that the light remains within the fibre.

In an optical fibre **total internal reflection** keeps the light within the fibre.

For total internal reflection the light must be incident at an angle greater than \( \theta_c \) where
\[
\sin \theta_c = \frac{n_2}{n_1} = 1/1.2 \quad \theta_c = 56.44^\circ
\]
6. A light ray is incident on the end of a straight optical fibre at angle $\theta_1$ and enters the fibre at angle $\theta_2$ (see figure). If refractive index of the fibre is 1.2, what is the maximum value of $\theta_1$ such that the light remains within the fibre.

$$\theta_c = 56.44^\circ$$

$$\theta_2 = 90^\circ - \theta_c$$

$$= 90 - 56.44 = 33.56^\circ$$

6. A light ray is incident on the end of a straight optical fibre at angle $\theta_1$ and enters the fibre at angle $\theta_2$ (see figure). If refractive index of the fibre is 1.2, what is the maximum value of $\theta_1$ such that the light remains within the fibre.

$$\theta_2 = 33.56^\circ$$

Now we can use Snell’s law to calculate $\theta_2$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\sin \theta_1 = 1.2 \times \sin 33.56 = 0.6634$$

$$\theta_1 = 41.56^\circ$$
6. A light ray is incident on the end of a straight optical fibre at angle \( \theta_1 \) and enters the fibre at angle \( \theta_2 \) (see figure). If refractive index of the fibre is 1.2, what is the maximum value of \( \theta_1 \) such that the light remains within the fibre.

\[ \theta_1 = 41.56^\circ \]

This angle is called the acceptance angle of the fibre. Only light that is less than 41.56° from the axis will get into the fibre.

Electrostatics Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI Unit</th>
<th>Other Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge (Q, q)</td>
<td>Coulomb (C)</td>
<td>electrons</td>
</tr>
<tr>
<td>Electric field (E)</td>
<td>N/C</td>
<td>(or V/m)</td>
</tr>
<tr>
<td>Electric Potential (V)</td>
<td>Volt (V)</td>
<td></td>
</tr>
<tr>
<td>Electric Potential Energy</td>
<td>Joule (J)</td>
<td>electron volt (eV)</td>
</tr>
</tbody>
</table>
The electron volt

The electron volt is a unit of energy or work.

It is the work done when one electron moves through one volt of potential difference.

By comparison, the SI unit of energy (the joule) is the work done when 1 coulomb of charge \((6.25 \times 10^{18} \text{ electrons})\) moves through 1 volt.

While it is not an SI unit it is commonly used in atomic and nuclear physics.

\[1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}\]

Symbols with multiple uses

- \(Q\) is used for both \text{Electric Charge} and \text{Heat}
- \(V\) is used for both \text{Volume} and \text{Electric Potential}
- \(P\) is used for both \text{Pressure} and \text{Power}
- \(c\) is used for both \text{specific heat capacity} and the \text{speed of light}
2. A positively charged rod is brought close to a neutral piece of paper, which attracts. Draw a diagram showing the separation of charge and explain why attraction occurs.

Charged Rod

Excess of positive charges

Paper – Equal number of positive and negative charges – no net charge,
2. A positively charged rod is brought close to a neutral piece of paper, which attracts. Draw a diagram showing the separation of charge and explain why attraction occurs.

Charged Rod

Excess of positive charges

As the paper gets close to the rod, negative charges are attracted and positive charges are repelled. A charge distribution results.

On average negative charges are closer to rod \((r_1)\) than positive charges \((r_2)\).

Force varies according to inverse square law \(F = kq_1q_2/r^2\)
2. A positively charged rod is brought close to a neutral piece of paper, which attracts. Draw a diagram showing the separation of charge and explain why attraction occurs.

\[ F_a = \frac{kq_1q_2}{r_1^2} \]

Force of attraction between positive and negative charges:

\[ F_r = \frac{kq_1q_2}{r_2^2} \]

Force of repulsion between positive charges:

Because \( r_2 > r_1 \), \( F_a \) will be greater than \( F_r \). Thus there is a net force of attraction between the rod and the paper.
3. Assume that the two charges shown below are 12.0 cm apart. Consider the magnitude of the electric field 2.5 cm from the positive charge. On which side of the charge – top, left or right – is the electric field the strongest? The weakest? Explain. Draw the electric field lines surrounding the two charges.

Electric field due to a point charge, is the electric force on a test charge divided by the test charge.

\[ E = \frac{k |q|}{r^2} \]

Electric field is directed away from positive charges and towards negative charges.
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First look at the electric field due to the **positive charge**.

\[ E = \frac{k |q|}{r^2} \]

Electric field is directed away from positive charges and towards negative charges.

Now add electric field due to **negative charge**.

\[ E = \frac{k |q|}{r^2} \]

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Field is strongest here since field due to both charges is in same direction.

Now add electric field due to negative charge.

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Field is weakest here since field due to charges are in opposite directions.

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Electric field is directed away from positive charges and towards negative charges.
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Field lines (blue) are closest together where the electric field is strongest.

4. A person scuffing here feet on a wool rug on a dry day accumulates a net charge of 42 mC (milli coulomb). How many excess electrons does she get, and how much does her mass increase?
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How many excess electrons.

One electron has a charge of $1.6 \times 10^{-19}$ C

So a charge of 42 mC ($42 \times 10^{-3}$ C)

$N$ (number of electrons) = charge / (charge of one electron)

$N = \frac{42 \times 10^{-3}}{1.6 \times 10^{-19}}$ electrons

$= 2.62 \times 10^{17}$ electrons

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To go on to calculate mass we just multiply this by the mass of an electron $m_e = 9.11 \times 10^{-31}$ kg

$m = 2.62 \times 10^{17} \times 9.11 \times 10^{-31}$

$= 2.38 \times 10^{-13}$ kg  (or $2.38 \times 10^{-16}$ kg for the μC case)
6. A proton is released in a uniform electric field, and it experiences an electric force of $3.75 \times 10^{-14}$ N towards the south. What are the magnitude and direction of the electric field.
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\[
\begin{align*}
\text{q} & \quad \rightarrow \quad \text{F} \\
& \quad \rightarrow \quad \text{E}
\end{align*}
\]

Relevant Formula is:

\[E = F/q\]

(Definition of electric field).

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\[E = F/q\]

We are given F. What is q (the charge of a proton)?
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\[ E = \frac{F}{q} \]

We are given $F$. What is $q$ (the charge of a proton)?

The charge on a proton is the same as the charge on an electron, only positive rather than negative.

\[ q = e = 1.6 \times 10^{-19} \text{ C} \]

\[ E = \frac{3.75 \times 10^{-14}}{1.6 \times 10^{-19}} \]

\[ = 2.34 \times 10^5 \text{ N/C} \]
6. A proton is released in a uniform electric field, and it experiences an electric force of $3.75 \times 10^{-14}$ N towards the south. What are the magnitude and direction of the electric field.

$$\begin{align*} 
q & \quad \Rightarrow \quad F \quad \Rightarrow \quad E 
\end{align*}$$

$$E = \frac{F}{q}$$

$$= 2.34 \times 10^5 \text{ N/C}$$

We also need to know the direction.

Electric field is always directed away from positive charges and towards negative charges. For a proton (positive charge) this is the same as the direction of the force.

A proton is attracted by negative charges. (For an electron the force would be opposite to the field).
6. A proton is released in a uniform electric field, and it experiences an electric force of $3.75 \times 10^{-14}$ N towards the south. What are the magnitude and direction of the electric field.

\[
\text{q} \rightarrow \text{F} \rightarrow \text{E}
\]

\[E = \frac{F}{q}\]

\[= 2.34 \times 10^5 \text{ N/C}\]

Direction is the same as that of the force – \textbf{towards the south}.

3. How much work does the electric field due in moving a proton from a point with a potential of $+125$ V to a point where it is $-55$ V. Express your answer both in Joules and electron volts.
3. How much work does the electric field due in moving a proton from a point with a potential of +125V to a point where it is −55V. Express your answer both in Joules and electron volts.

Work done by an electric field:

\[ W = q \Delta V \]

The charge on a proton we know from the last question
\[ q = e = 1.6 \times 10^{-19} \text{ C} \]
3. How much work does the electric field due in moving a proton from a point with a potential of $+125\text{V}$ to a point where it is $-55\text{V}$. Express your answer both in Joules and electron volts.

\[
W = q\Delta V
\]

\[
= 1.6 \times 10^{-19} \times (V_A - V_B)
\]

\[
= 1.6 \times 10^{-19} \times (125 - (-55))
\]

\[
= 1.6 \times 10^{-19} \times 180
\]

\[
= 2.88 \times 10^{-17} \text{ J}
\]

3. How much work does the electric field due in moving a proton from a point with a potential of $+125\text{V}$ to a point where it is $-55\text{V}$. Express your answer both in Joules and electron volts.

We are also asked for the value in electron volts.

Since $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

\[
W = 2.88 \times 10^{-17} \text{ J} = \frac{2.88 \times 10^{-17}}{1.6 \times 10^{-19}}
\]

\[
= 180 \text{ eV}
\]
3. How much work does the electric field due in moving a proton from a point with a potential of +125V to a point where it is -55V. Express your answer both in Joules and electron volts.

\[ W = q\Delta V \]

To calculate \( W \) in eV we can use this formula with \( q \) measured in electrons (not Coulombs). Charge of a proton is one electron charge.

\[ W = 1 \times (125 - (-55)) \]
\[ = 180 \text{ eV} \]