# Equations & quantities reference

### Given equations

Note that the guides and units are not given.

s = (u+v)t \* 0.5 [-a]

v = u + at [-s]

s = ut + 1/2at² [-v]

v² = u² + 2as [-t]

F = ma

W = mg

p = mv [p: momentum]

v = s / t [@ a = 0]

ΔW = F \* Δs [Work done J]

KE = 1/2mv² [J]

GPE = mgΔh [Gravitational potential J]

P = E / t = W / t [W]

Efficiency = Useful out / Total in

ρ = m / V [ρ: density]

F = 6(pi)ηrv [η: viscosity] [stroke's law] [v: terminal velocity]

ΔF = k Δx [Δx: extension][k: stiffness constant][hooke's law]

ΔEelastic = 1/2 FΔx

E = σ / ε [Young modulus]

σ = F / A [Stress]

ε = Δx / x [Strain]

v = fλ [Transverse wave speed]

v = sqrt(T/μ) [Wave speed on string] [T: Tension] [μ: kg m²]

I = P / A [Intensity of radiation] [A: Area m²]

nsinθ = nsinθ [Snell's law]

n = c / v

sinC = n⁻¹ [Critical angle]

nλ = dsinθ [d: slit width] [n: index of fringe] [θ: angle to fringe] [d = 1 / num of gratings]

V = W / Q = E / Q [Potential difference] [Q: charge]

V = IR

P = VI = I²R = V² / R

W = VIt [Work done J]

R = ρl / A [ρ: Resistivity] [l: length]

I = ΔQ / Δt [Q: charge]

I = nAve [A: Area m2] [n: density of electron]

E = hf

hf = Φ + 1/2mv² [Φ: work function] [v: maximum velocity]

λ = h / p [λ: de broglie wavelength]

### Given quantities

g = 9.81 ms-2

e = -1.6e-19 C

mass of e = 9.11e-31 kg

eV = 1.6e-19 J

h = 6.63e-34 Js

c = 3e8 ms-1

### Not given equations

Equations not given in the exam

Angle to horizontal, component: Hori = cosθ & verti = sinθ, Angle to vertical: Flip

mg / 2 = Tsinθ [T: Tension of string on one side]

p1 + p2 = 0 [pn: momentum of the nth object]

∑cw moment = ∑acw moment

upthrust = weight of fluid displaced = ρ(f) V(s) g

Terminal v = 2r²g(p(s) - p(f)) / 9η

sinC = n(to) / n(from) [C: critical angle of material(from)]

n1v1 = n2v2 [Refraction between mediums]

Δx = λ / 2π \* Δφ [Δx: path difference] [Δφ: phase difference]

n <= d / λ [n: maximum order of fringe]

total parallel resistance R = (∑R⁻¹)⁻¹

V(d) = V(t) \* (R/R(t))` [V(d): pd at a device] [R/V(t): Total values]

Rt = R + r [r: internal resistance]

ε = IR + Ir

### Conversions

1 kWh = 3.6e6 J

1 km/h = 3.6 m/s

1m = 1e-9 nm

### SI Base units

|  |  |  |  |
| --- | --- | --- | --- |
| **Unit** | **Name** | **Quantity** | **Symbol** |
| s | seconds | time | t |
| m | meter | length | l,x,d |
| kg | kilogram | mass | m |
| A | ampere | electric current | I |
| K | kelvin | temperature | T |
| mol | mole | amount of substance | n |
| cd | candela | luminous intensity | Iv |

### Misc

|  |  |
| --- | --- |
| **Problem** | **Answer** |
| Usefulness of dataloggers | - Small changes of values can be measured accurately  - Easy processing of data |
| Measuring lengths under 1cm (e.g. diameter of string) | Micrometer |
| Larger acceptable error range | Exact value is uncertain for measured object |
| Why use an oscilloscope instead of hearing? | - Hard for person to judge volume level  - the oscilloscope can measure amplitudes more accurately |
| Difference between SI unit and SI base unit? | - SI Base unit is the combination of base units to make the quantity  - SI unit is the unit to represent the quantity |

# Topic 1 - Force & motion

## Motion & forces

Free fall - Only weight is the force acting on the object

Work done - The energy transferred by a force moving over a distance

### Newton's laws of motion

1. An object will remain at rest or uniform motion until acted upon by a resultant force

2. F = ma

3. when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction

The **normal contact** force’s pair acts on **the surface**

The **gravitational** force pairs with the **weight** which acts on **the earth’s mass**

#### When used in explanations:

1. Used to explain resultant forces and movement

2. Calculations

3. Used to explain collisions and force exertions

### Free fall

Only weight is the force acting on the object

The **gravitational field strength** is **G-Force per unit mass (ma / m = a)**

The **gravitational force** is **GPE per unit length (mgh / h = mg = F)**

### Work done

The energy transferred by a force moving over a distance.

### Frictional forces

For a moving object:

The f-force **object → on surface** is **opposite to direction** of motion

The f-force **surface → on object** is **in the direction** of motion

### Lift & scale scenario

Rx

W

Rx

W

N

For a lift initially moving downwards at a constant velocity:

1. The scale on the lift is the normal force on person by scale

1. *(scale reading = upward force of person)*

1. Net force = 0 on the person at constant velocity
2. Reading → W of person
3. Decelerate → resultant upward force on person

4. *(in order to decelerate, an upward force must be applied)*

1. → ↑ reaction force on person

5. *(reaction force = Rx + N)*

1. Reading → > W of person

## Types of quantities

|  |  |  |
| --- | --- | --- |
| **Type** | **Description** | **Example** |
| Scalar | Only has a magnitude | Speed, distance, temperature |
| Vector | Has both magnitude & direction | Velocity, displacement, acceleration |

### Moments

The principle of moment - Body -> eq if ∑ CW moment = ACW moment

Center of gravity - The point at which weight is taken to act.

Principle of conversation of energy - Energy cannot be created or destroyed, but can be transferred from one form to - another

Equilibrium - The situation for a body where there is 0 resultant force & moment

### Momentum

Conversation of momentum - Total moment before and after collision is the same, provided that no external forces - act

When explaining in terms of momentum, state the initial momentum & the final momentum. The momentum of the actor is opposite in direction to the momentum of the object.

## Collisions

### Types of collisions

|  |  |
| --- | --- |
| **Types** | **Condition** |
| Elastic | KE conserved |
| Inelastic | KE not conserved |
| Perfectly inelastic | Objects stick to each other |

## Explaining force changes

**When a type of force changes:**

1. Which force is greater
2. Net force direction
3. Motion of material

# Topic 2 - Materials

## Fluid movements

Upthrust - The weight of the fluid displaced by an object

Viscous drag - The magnitude of the force of viscosity acting on a spherical body, assuming stroke's - law is applied

Terminal velocity - The constant max velocity of falling object when resultant force = 0

### Viscosity & flow

Hooke's law - Δx is directly proportional to F applied

Viscosity - How resistant a fluid is to flowing. Viscosity is **temperature dependent**!

Lower viscosity → Liquid can flow greater distances in the same time

Liquids: T ↑ η ↓

Gases: T ↑ η ↑

### Flow types

Laminar flow - fluid velocity at a fixed point remains constant

Turbulent flow - fluid velocity charges overtime in unpredictable manner, whorls are formed, material - circulates around the edge

## Young modulus, stress and strain

### Types of deformations

|  |  |  |
| --- | --- | --- |
| **Types** | **Appearance after deformation** | **Molecular level behavior** |
| Elastic | Object → Original shape (Reversible) | Atoms moved apart but return to origin |
| Plastic | Object → Permanently deformed | Atoms moved apart and does not return to origin |

### Stiffness constant

A measure of how difficult it is to stretch a given object.

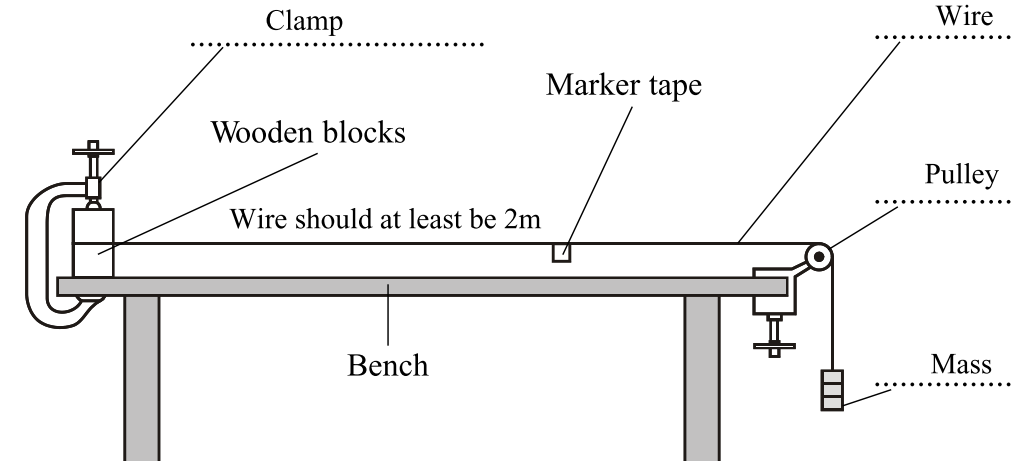
- Note that the **stiffness for a material is constant** for an object

- The stiffness changes per material & shape

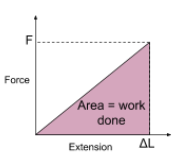
### F = kΔx

The extension halves if there are 2 set of ropes. (e.g. 2 connected springs)

### Determining the young modulus



## F-Δx graphs

Involved equations to derive following: ½FΔx & F = kΔx

The **area** under the graph is the **elastic strain energy**

The **slope** of the graph is the **stiffness constant**

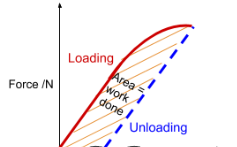
### Graph behaviors

A F-Δx graph can show loading and unloading behaviors.

∵stiffness constant for a material is constant ∴ the loading and unloading lines is parallel

The **area between loading and unload lines** is the **work done →** permanently deform the material

The **area from origin to end** is the **work done** → stretch the material to fracture.



## Stress / strain graphs

∵Young modulus = Stress / Strain

**Slope** of the graph is the **Young modulus**

**Area under the graph** is the **energy absorbed**

### Explaining

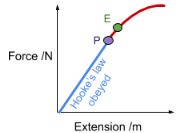
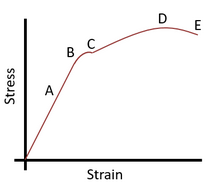
State features of the graph such as

1. Slopes

2. Area under the graph

3. Termination points

Access **similarities and differences** → **link features to the actual object** with the corresponding quantities



#### A - Limit of proportionality

The point at which stress is too great which halt's the application of Hooke's law

↪Hooke's law doesn't apply.

#### B - Elastic limit

Max strain for which material will return to original length

↪Material is permanently deformed.

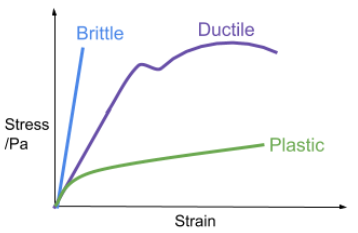
#### C - Yield point

↪Material undergoes a sudden increase in extension

#### E - Breaking stress

The maximum stress a material can withstand without breaking

↪Material breaks.



The shape of the stress strain graph can also show whether a material is:

* **Brittle** Shatters without deformation. Is able to extend very little, so more likely to break at a lower strain
* **Ductile** Can be pulled into a long thin shape
* **Plastic** Does not return to original shape when deformed & force removed

If a material is **strong**, a large force is required to break it.

# Topic 3 - Waves & light

## Wave properties

Superpositions - displacements of two waves are combined as they pass each other

Coherence - same f, λ and constant wave difference

Wave fronts - Planes which all the points are in phase

|  |  |
| --- | --- |
| **Property** | **Definition** |
| Amplitude | A wave’s max displacement from it’s eq pos |
| Frequency | The num of waves that pass a point in a unit time period |
| Wavelength | The displacement between two identical positions on two adjacent waves |
| Period | Time taken for a wave to complete one full cycle |

the angle of incidence and refraction are **taken from the normal**

## Wave types

### Transverse waves

- They oscillate **perpendicular** to their direction of energy transfer

- Made up of crests and troughs

### Longitudinal waves

- They oscillate **parallel** to their direction of energy transfer

- Made up of rarefactions and compressions - can't travel in vacuum

### Stationary waves

They are **formed from the superposition** of 2 waves:

1. Traveling in opposite directions,

2. in the same plane,

3. having the same f, λ and A

Note that **no energy is transferred** by a stationary wave

#### Points on stationary waves

A non-node point on a stationary wave **vibrates** at the same vertical plane.

A node point on a stationary wave remains stationary

A stationary wave’s wavelength is the distance between 3 node points. So the picture on the right is 0.5λ

#### Pasted image 20220313123118Drawing stationary waves

When drawing stationary waves, remember not to draw 2 solid lines

## Wave phenomenons

Only waves can show **Interference** and **Diffraction**

### Interference

Waves that have the same f, A, λ can exhibit interference

- **Constructive** - in phase - antinodes formed - maximum displacement

- **Destructive** - out of phase - nodes formed - no displacement

### Diffraction

d↓ λ↑ -> θ↑ from dsinθ = nλ

**The wavelength must be comparable to the slit width**

#### Double slit / Diffraction grating experiment

* A monochromatic light source (single wavelength) is used
* The slits acts as **coherent** sources of light
* The slits should be narrow to product a better diffraction effect
* The slits should be evenly spaced to the point source to be coherent

#### If a white light is used

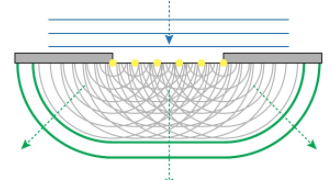
* Center fringe would be white
* Side fringes are spectra, where violet is on the side nearest the center

#### Maximum order of fringe

Substitute sinθ <= 1 to dsinθ = nλ → n <= d / λ

#### To obtain the wavelength of a light source

- Use dsinθ = nλ

- Measure d using 1 / num of gratings

- Measure the angle to orders of beam

- Measure θ using tanθ = x / D or a protractor with great accuracy (0.5º)

- Measure values with variations to D/n to improve accuracy

#### Huygens' principle

Every point on a wavefront is a point source to secondary wavelets

It can be used to predict the wave form. When drawing, make sure the circles' radius is the wavelength.

### Refraction

Change in direction due to change in medium

*Light waves*

→ denser medium: bends → normal: v ↑

-> less dense medium: bends ← normal: v ↓

i = C, r = 90º along the boundary

*Water waves*

→ shallow medium: bends → normal: v ↓

→ deeper medium: bends ← normal: v ↑

#### Total internal reflection

The refractive index of a material is proportional to the density

TIR only occurs when i > C and dense → less dense (n1 > n2)

### Polarization

*Waves polarized upon diffraction of flat surface:*

diffract → medium: vertically polarized

reflect outside: horizontally polarized

* Polarization only happens to transverse waves.
* Unpolarized waves vibrates at all directions.
* Polarized wave vibrate in **one plane including direction of travel**

#### Radio waves & polarization

Transmitted radio waves are polarized, so aerial rods must be aligned in the same plane of the wave to receive the signal

#### Stress-detection & polarization

1. Filters at 90º to each other blocks light
2. Stress-points rotates the plane of polarization allowing light to pass
3. Darker areas are parts with less stress

### Reflection

When the density change, waves are reflected from the boundaries of two mediums.

## Pasted image 20220312174509Diffraction of electrons

When electrons passes through the gaps on atoms, it produces a diffraction pattern as following:

### de Broglie wavelength

It is a useful property for particle/wave-behaving objects

### Electroscopes

Electrons at same speeds will be focused uniformly.

The wavelength of 5% c electrons have λ similar to size of atoms, so diffraction occurs.

### Crispness of an image

v ↑ λ ↓ resolution ↑

#### Comparing microscopes and electroscopes

The wavelength of the light is around e-7. The blurriness of image produced from a microscope is dependent on the wavelength, as more diffraction will distort the images.

In a electroscope, it is more crisp since the wavelength of electrons is around e-10

## Ultrasound pulse-echo

#### A ultrasound pulse-echo works by:

* concept: **Reflection**
* t measured for wave to travel back and forth detector, so
* Speed known

#### A higher frequency is used because

* c = fλ, f ↑ λ ↓
* Resolution / crispness of image ↑
* If ultrasound is used to detect Δ densities in medium, this can detect smaller bubbles of such medium.

## Using oscilloscope to measure speed of sound

1. *Move* the speaker → waves are in phase → measure distance from 0cm
2. *Move* speaker again → waves are in phase
3. *Measure & calculate* moved distance → λ
4. *Measure* T: read the oscilloscope for **time taken** to complete oscillation
5. v = λ / T

## Intensity of radiation

If the radiation is emitted from a device, the area from a distance can be calculated by (surface area of sphere)

## Pasted image 20220313154241Electromagnetic waves

All electromagnetic waves are transverse & travel at 3e8ms-1 in vacuum & air

The vibrations of electric & magnetic waves are:

1. Perpendicular to each other

2. Oscillate **in one direction** & perpendicular to direction of travel

3. In phase with each other

## Photoelectric effect

Photon - Particle of energy

Photoelectrons - Electrons emitted from photoelectric effect

The emission of pe- from a metal surface when light above the threshold frequency is shone on it

For , the KE can be replaced by work done from , where the charge is the charge of an electron

Light intensity ↑ Photons emitted ↑ Electron emitted ↑ Current ↑

#### Explanation of photoelectricity (wildcard)

* There is a threshold frequency for photoelectric emission
* Light consists of photons, and the energy of a photon is proportional to the frequency of light
* 1 e⁻ near surface of metal absorbs 1p⁺ -> gain energy hf
* work function Φ is the minimum energy required to escape
* hf > Φ -> e⁻ has enough E to escape

#### Threshold frequency - The min. f of p+ required to emit pe- from the surface of the metal plate.

Work function - The min energy required to release a pe-from metal surface

#### Why threshold frequency?

1. Photon energy E = hf
2. Photon energy must be greater than Φ to release electron
3. If asked about wavelength, state existence of min f → max λ

#### KE-f graphs

The **K-intercept** of the graph is **negative work function**

The **slope** of the graph is **h**

### Experimental setup of photocells

1. Photon energy > work function @ cathode
2. Photon release e- at cathode, e- travel → anode making a current
3. e- released with **range** of KE
4. KE ↑ Reverse pd ↑
5. Forward pd ↑ → Vs; enough to stop e- w/ max KE

The stopping potential Vs = KEmax in eV

## Wave-particle duality

#### Prove of particle nature when electrons are emitted instantly in photoelectricity

1. One photon is being absorbed by one electron.
2. Photon transfer all their energies to electron

### The prove for particle nature

1. Photoelectricity

2. Observation: not all frequencies of light can cause emission of photoelectrons, hence the **threshold frequency**

3. This can be explained by photon by hf > Φ

4. Wave theory suggests that any frequency of light should be able to cause emission of photoelectrons

2. The emission of electrons is instantaneous, but wave theory suggests that there will be a delay

3. The kinetic energy depends on frequency, but wave theory suggests that it depends on the intensity of light.

#### Explaining how observations prove the particle nature

1. Particle theory: the energy hf of photon > work function to emit electrons

Wave theory: when enough E absorbed electrons will be released regardless of f - **NOT SEEN**

1. Particle theory: one photon releases one electron

Wave theory: there is time needed to absorb the energy - **NOT SEEN**

1. Particle theory: energy of photon is E = hf → One photon releases one electron giving it KE → f ↑ e- KE ↑

Wave theory: energy depends on intensity → Intensity ↑ KE ↑ - **NOT SEEN** → Intensity ↑ e- ↑ KE unchanged

### The prove for wave nature

1. Interference / diffraction

2. Bright and dark fringes of a double slit interference experiment

3. Bright fringes occurs when path difference is nλ, dark fringes occurs when path difference is 0.5nλ

4. Particle theory suggests that there will be no diffraction, and only two bright fringes will be seen

## Energy levels and atomic line spectra

Excited - Atoms gains energy and move up energy levels

Energy levels - Specific allowed energies

* Energy levels are specific
* If an electron gains enough energy, it excites and move up one level.
* Shortly after it returns to the original energy level & releases a **photon** with the gained energy.
* Photons can only excite electrons if the energy matches an energy level difference

### Line spectrum

Line spectra - Emission of specific frequencies

The photon’s energy is proportional to the frequency of the photon, this frequency is displayed in the spectrum.

Each energy level is called an **energy level band**

#### Cause of line spectrum

* In a light tube: e⁻ accelerated -> gas atoms excited & de-excited -> releasing photons
* Passing the light from the light tube through a diffraction grating, a **line spectrum** is produced.
* The spectrum is seen to contain only **discrete values of wavelength**

#### Pasted image 20220312182826Why are there certain wavelengths only?

* Atom’s energy levels are specific
* So there are only certain **energy level differences**

# Topic 4 - Electric circuits

## Circuit basics

Current - Rate of flow of charge particles

emf of a cell - The energy supplied to the whole circuit per unit charge

Drift velocity - Averagevelocity of charge carriers

Ohm’s law - The I & V is directly proportional through an Ohmic conductor. R being constant

Ohmic conductor - A conductor following Ohm’s law.

### Principle of charge conservation

The total electric charge in a closed system does not change

↪ The total current flowing into a junction is equal to the current

flowing out of that junction.

#### Distribution of current in circuits

- Series: I constant **if physical properties are unchanged**

- Parallel: ∑I in all branches = I(t)

### Principle of conversation of energy

According [[Topic 1 - Force and motion#Principle of conversation of energy|principle of conservation of energy]], we can derive that the total energy in a closed system stays constant

#### Distribution of potential difference in circuits

- Series: ∑V = emf

- Parallel: V across branches is the same

### Resistances

#### Series - ∑R

Derivation

Vt = ∑V *∵ V = IR*

Vt = ∑IR *∵ I is a factor*

Vt = I(∑R)

Rt = ∑R

#### Parallel - (∑R⁻¹)⁻¹

Derivation

It = ∑I *∵ V/R = I ∵ sum of current in a parallel is the total current*

It = ∑(V/R) *∵ V is a factor*

It = V(∑R⁻¹)

Rt⁻¹ = ∑R⁻¹

Rt = (∑R⁻¹)⁻¹

### Potential difference

Potential difference in base units only can be derived from

## I-V graphs

Since V = IR, the slope of a I-V graph is R⁻¹, so the slope of a V-I graph is R

|  |  |
| --- | --- |
| **Conductor type** | **Graph** |
| Ohmic conductors Since Ohmic conductors respect V = IR at all times, the line is straight through the origin | Pasted image 20220312193852 |
| Semiconductor diode After passing a small bias, the threshold voltage, the current can **flow easily in the forward direction**.  In the reverse direction, the **resistance is extremely high** so that only a **minimal current** can flow | IMG_258 |
| Filament bulb The metal wire heats up as current increases  Initially heating effect is minimal, so V=IR is respected  Temperature ↑ Resistance ↑, so graph starts to curve down  Note that the effect of temperature is dependent on the conduction material | IMG_257 |
| Negative temperature coefficient thermistor The metal wire heats up as current increases  Initially heating effect is minimal, so V=IR is respected  Temperature ↑ Resistance ↓, so graph starts to curve up  This component acts in the opposite way to a filament bulb | IMG_256 |

## Resistivity

A measure of how easily a material conducts electricity

### Resistivity and resistance

For resistivity, the value is the same for any size & shape. Resistance changes with the size and shape. Both values will be affected by temperature

## Potential divider circuits

A circuit with several resistors in series connected across a voltage source

### Potential difference at a device

V(d) = V(t) \* (R/R(t)) where V(d) is the device's pd, V(t) and R(t) are the total values for respective prefix

### Determining the internal resistance of a cell

Using , the r of the cell can be found.

By polling a V-I graph

The **y-intercept** is **emf**

The **negative slope** is **r**

## Electric circuit resistors

### What affects resistance

The resistance of a component depends on:

1. The intensity of vibrations of atoms in a material

2. Number of charge carriers (released)

### Different resistors and the factors

#### Light dependent resistor (LDR)

A resistor which when Light intensity ↑ Resistance ↓

**Relationship with photoelectric effect**

- LDRs are made from photoconductive materials

- Light intensity ↑ → electrons released → number of charge carriers ↑ resistance ↓

#### Metallic conductors (Filament bulbs)

Voltage ↑ Current ↑ Temperature ↑ → intensity of vibrations of atoms ↑ rate of collision of atoms and electrons ↑ resistance ↑

#### Negative temperature coefficient thermistors

Voltage ↑ Current ↑ Temperature ↑ → electrons gain energy → number of charge carriers ↑ I=nAve, current ↑ resistance ↓

### Charge carrier densities

The same type of material have the same charge carrier density.