printf("Hello World");

Modern Physics

1. Possibe products of 2 vectors

Scalar - quantiti that is completely specified by a number and its unit, has magnitude, no direction obey normal algebra

Vector - quantiti that is speciefied by magnitude and direction in space, obey vector algebra

Scalar product - result is a scalar

$$\bar{a} \circ \bar{b} = |\bar{a}||\bar{b}|\cos\Theta$$ Θ angle betwen $\bar{a}$ and $\bar{b}$

analitical formula

$$\bar{a} \circ \bar{b} = a_x b_x + a_y b_y + a_z b_z$$

Vector product - result is a vector

$$\bar{a} \times \bar{b} = \bar{c}$$

properties:

1) $|\bar{a} \times \bar{b}| = |\bar{a}||\bar{b}|\sin\Theta$ 2) $\bar{c} \perp \bar{a} \wedge \bar{c} \perp \bar{b}$

3) $\bar{a}$ and $\bar{b}$ compose right-handed system

analitical formula

$$\bar{a} \times \bar{b} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

Nebula operator ∇

- applied to scalar function, behaves like multi. of vector by scalar, result is vector – gradient
$\nabla\varphi$

- applied to vector fun. as scalar product, result is scalar – divergence
$\nabla \circ \bar{a}$

- applied to vector fun. as vector product, result is vector – rotation (curl)
$\nabla \times \bar{a}$

The four Maxwell's equations

I. The Gauss's law for electricity

Electric flux $\Phi_{E,S}$ flowing through a closed surface is proportional to sum of all electric charges inside this surface

II. The Gauss's law for magnetism

If no sources of magnetic fields the magnetic flux $\Phi_{B,S}$ flowing through closed surface must be 0

III. The Faraday's law of induction

Changing magnetic field produces an electric field

IV. The Ampère's law

Flowing electric current and time-varying electric field, both produce magnetic field

2. Light waves, Poynting's vector

Light is an electromagnetic field. Visible light have limits of wavelength from ~400 nm (violet) to ~700 nm (red)

- Infrared - emitted by atoms or molecules when their change their motion
- Microwaves
- Radiowaves
- Ultra violet
- γ rays
- Gamma rays

Amplitudes of electric and magnetic fields in electromagn. waves are interrelated with each other

$$c \approx 300\,000\,000 \frac{m}{s}$$ - speed of light in vacuum

ε - electric constant

μ - magnetic permeability

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$! - speed of light in vacuum

$$v = \frac{c}{\sqrt{\varepsilon_r}}$$ - speed of light in matter

Poynting vector - $\bar{S}$

Electromagnetic wave can transport energy, the magnitude and direction of the energy flow in an electromagnetic wave is described by Poynting vector

$$\bar{S} = \bar{E} \times \bar{H} = \frac{1}{\mu_0} \bar{E} \times \bar{B}$$

$\bar{E}$ and $\bar{B}$ - fields of wave at particular point in space

$\bar{S}$ is time dependent vector

Luminescence - phenomenon of emitting light by objects not because of their temperature but of various excitations. We can distinguish 2 subtypos:

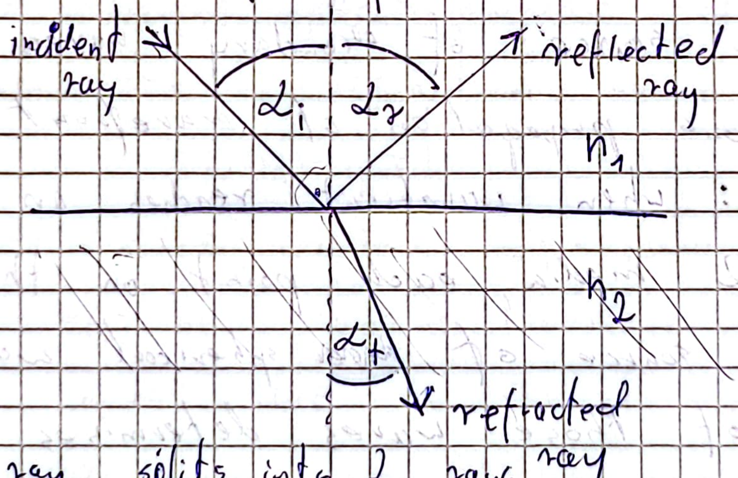
- fluorescence: emission of light ends immidiatly after excitation ends
- phosphorescentces: objects glow for some time after excitation

3. Three laws of geometrical optics

I The law of rectilinear propagation

In homogeneous medium light travels along straight paths. Thus a opaque objects placed betwen source of light and screen will cast a shadow with sharply boundaries.

II and III laws of reflection and refraction



$\alpha_i = \alpha_r$

Incident ray splits into 2 rays

1) Incident, reflected and refracted rays lay in one plane, called the plane of incidence, it is perpendicular to the boundary surface.

2). Incident and reflected rays form equal angle with normal to the boundary surface

3) $\frac{\sin \alpha_i}{\sin \alpha_t} = n_{21}$ $\quad n_{12} = \frac{1}{n_{21}}$ - relative index of refraction

reversibility of light

this means that if light is passing in opposite

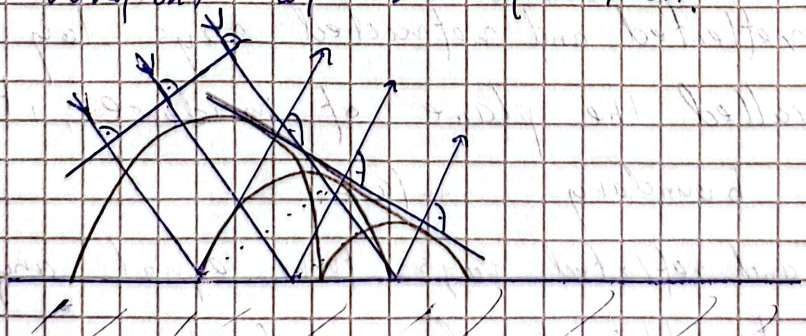
Snell's law $\frac{\sin \Theta_1}{\sin \Theta_2} = n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

Total internal reflection - when light is passing to optically less dence medium (lower n), starting from a certain angle called critical angle of total internal reflection, all light is being reflected

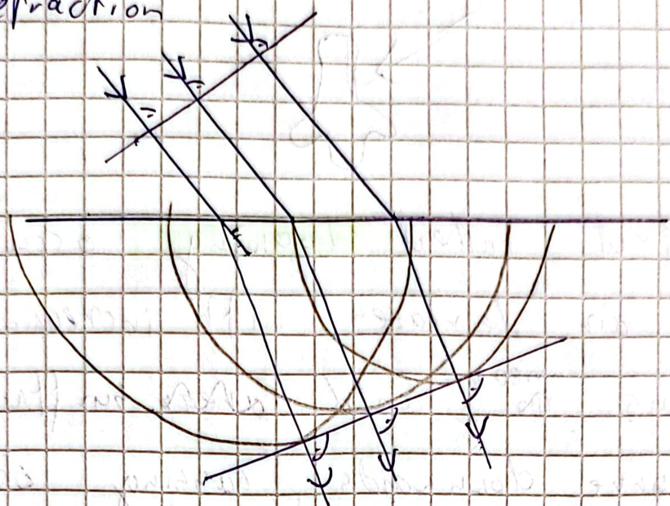
4. The Huyggens principle - formulation and application

According to this principle, every point ~~of~~ on a wavefront can be considered as a source of secondary spherical waves that propagate in all directions. The envelope of those secondary waves at a given moment forms the new wavefront

- rectilinear propagation : when light travels in a straight line each point on the wavefront acts as a source of secondary waves, resulting in continuous propagation of wavefront
- reflection : when wavefront reaches an interface between 2 media, each point on the wavefront acts as a source of ~~secon~~ spherical waves. The envelope of those waves determines the new wavefront after reflection.



- refraction: wavefront reaches an interface between 2 media, each point acts as source of secondary ~~one~~ wave. The envelope of those waves determines new wavefront after refraction



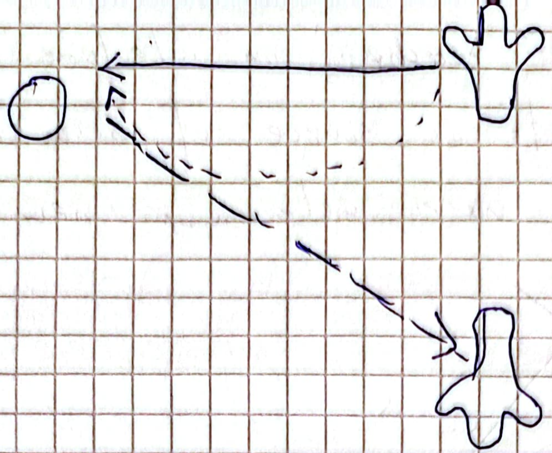
6. Propagation of light in nonhomogeneous media - explanation of mirages

In nonhomogeneous medium, the velocity of light propagation varies from point to point so we have to ~~see~~ describe optical properties of medium by giving the index of refraction as a function of possition

$$n = n(x, y, z)$$

So the refractive index varies, and as a result light waves no longer travel in straight lines, but in curve ones due to varing refractive index.

Mirages occur when the Earth's surface is heated, causing layers of air near the ground warmer and have higher refractive index. As a result light waves passing through this region are curved upwards. When an observer looks at the object, light can reach his eyes can travel both straight and curved paths. This lead to 2 images: 1st of actual position and 2nd inverted image looking like it was reflected by water



Mirage

A similar effect called looming occures when the density of air decreases with increasing heigh whic usually happens ~~on~~ near cold ~~areas~~ surffaces. The light rays curve downwards, causing objects to appear elevated. ~~or larger than they cause~~ or longer than they actualy a

5) The Fermat's principle - formulation and application

Fermat's principle states that light always take the minimum optical length when traveling from point to point

For reflection, when light ray goes from A to B after being reflected at D, Fermat's principle states that the path taken by light is the shortest path from all paths connecting A an touching surface D.

For refraction, it is simillar, when light passes from 1st medium of n_1 to 2nd of n_2, the path taken to travel from point A to B has the minimum optical length.

! Dispersion - dependence of refraction index on wavelength.

The rainbow is caused by dispersion of white light in water. The rainbow is a result of superposition of colored beams from all water drops.

7. Interference

Interference - when identical waves from 2 sources overlap at a point of space, the combined wave intensity at that point can be greater or less than intensity of either of 2 waves.

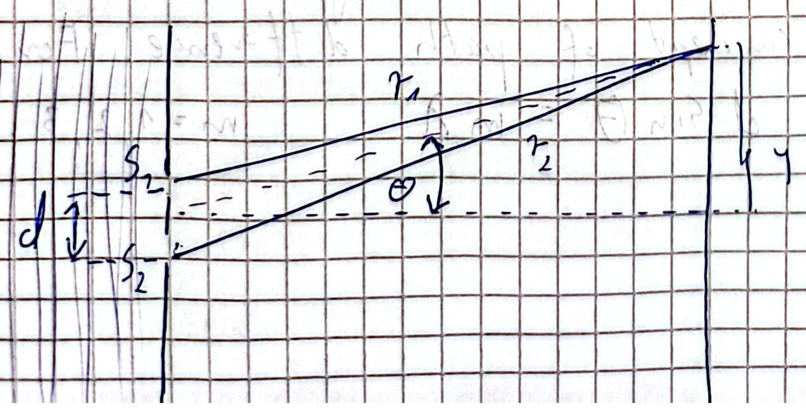
Case of double-slit interference - single light source is divided into 2 components that act as independent sources. When these waves pass through 2 slits and overlap, they create an interference patern on the screen.

For constructive interference, the path difference between the 2 waves must be equal to an integer multiple of the wavelength.

$$d \sin\Theta = m\lambda \qquad m = 0, 1, 2 \ldots$$

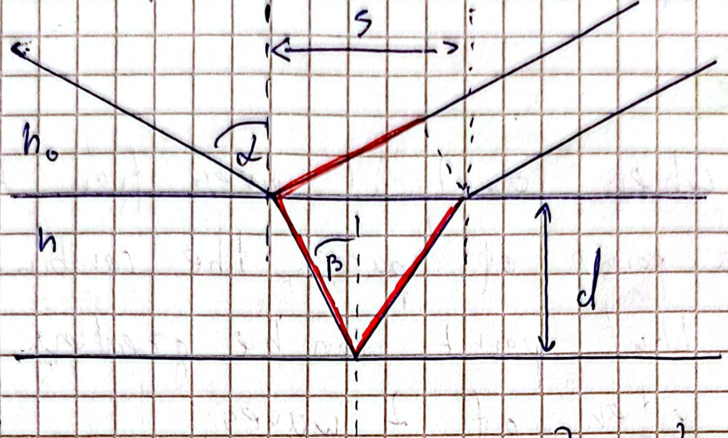
For deconstructive interference, the path difference must be equal to a half-integer multiple of λ

$$d \sin\Theta = \left(m + \tfrac{1}{2}\right)\lambda \qquad m = 0, 1, 2 \ldots$$



Interference in thin films

The interference pattern arises due to the reflection and transmision of light at different interfaces. The optical path diff between the reflected and transmitted waves determines pattern.



$m=0,1,2$

interference maxima: $m\lambda_0 = 2nd\cos\beta - \frac{\lambda_0}{2}$

to calculate dependency on α we use Snells law

⇓

max $2d\sqrt{n^2 - n_0\sin^2\alpha} = (m+\frac{1}{2})\lambda_0$

min $2d\sqrt{n^2 - n_0\sin^2\alpha} = m\lambda_0$

8. Diffraction gratings

Diffraction gratings are optical devices consisting of a large number of evenly spaced parallel slits. When light passes through a diffraction grating, it undergoes ~~diffrak~~ ~~interferenety~~ interference, resulting in formation of diffracted ~~pa~~ fringes. Condition for diffraction fringes can be derived using the concept of path difference. For constructive interference $d\sin\Theta = m\lambda$ $m=1,2,3\ldots$

Dispersion of grating referes to the phenomenon where different wavelengths of light are spread out or separated. A diffraction grating exhibits dispersion because it produces a distinct diffraction angle for each wavelength. It is used in spectoscopy to separate and analize the components of light.

$D = \frac{m}{d \cos \theta}$

Resolving power R $\quad R = \frac{\lambda}{\Delta\lambda} = N \cdot m$ $\quad$ m - order number

$\Delta\lambda$ - smallest separation bet. 2 lines in a spectrum

The resolution power, like dispersion increases with the order number. But unlike the dispersion, R is proportional to the number of lines N whereas is independent of their separation d

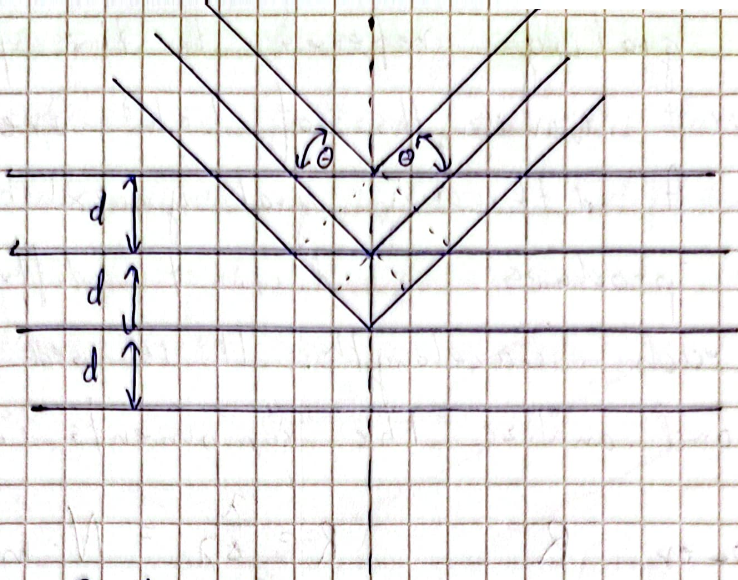
Dispersion and resolving power measure different aspects of a diffraction grating's ability to produce cleanly separated lines

9. Bragg law - X-ray diffraction

When X-rays pass through a crystal, they undergo a phenomenon called X-ray diffraction. Crystals have a regular arrangements of atoms, which acts as a diffraction grating for X-rays. The atomic planes ~~set~~ within crystal acts as the parallel slits, causing the X-rays to diffract and form a pattern of constructive and descrutive interference

2d

Bragg's ~~for~~ law is widely used to determine the atomic



$$2d \sin\theta = m\lambda$$

10. Holography

Holography - both the amplitudes and phases of the wave fronts are preserved on a photographic plate. While a photography projects a 3D objects onto 2D format, a hologram preserves the info on 3D nature of the object.

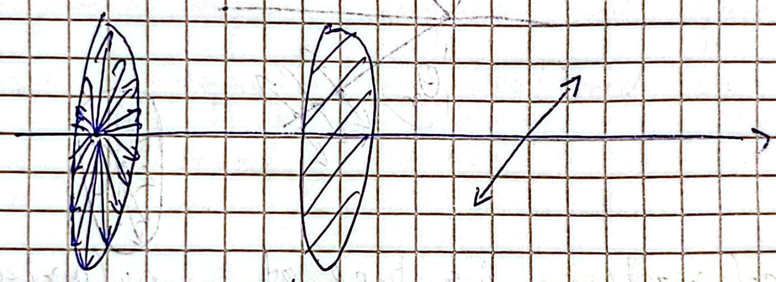
The process of creating a hologram involves illuminating the object with a laser beam, which acts as the object wave. Simultaneously, a reference beam is directed onto a phodographic plate. The 2 beams intersect and create an interference patern on the plate. The interference pattern recorded on the plate contains all necessary info. about objects structure, shape, texture etc. When the hologram is illuminated with the same reference beam used during its creation, the interference patern diffracts the light, reconstructing the orginal objects wavefront.

Electromagnetic waves are transverse waves because ~~here~~ their electric field vector E and magnetic field vector B are perpendicular not only to each other but also to direction of propagation

11. Polarisation of light

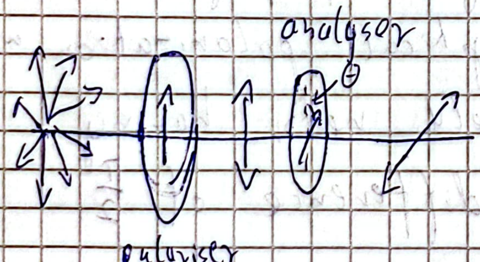
Natural light is unpolarized - there is no preferred plane containing the E vector.

Linear polarisation - electric field vetor E of electromagnetic wave remains only in one fixed direction. The plane containing vector E and direction of propagation is the plane of polorization.



Polorizer

Malus's law



$$E = E_0 \cos\theta$$

$$I \propto E^2$$

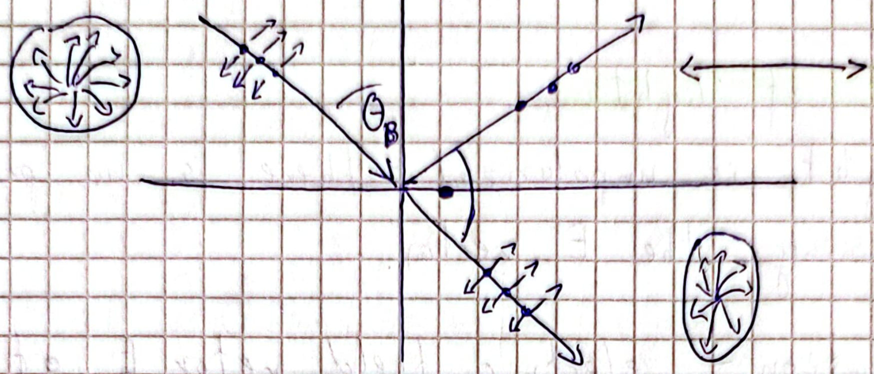
$$E^2 = E_0^2 \cos^2\theta$$

$$I = I_0 \cos^2\theta$$

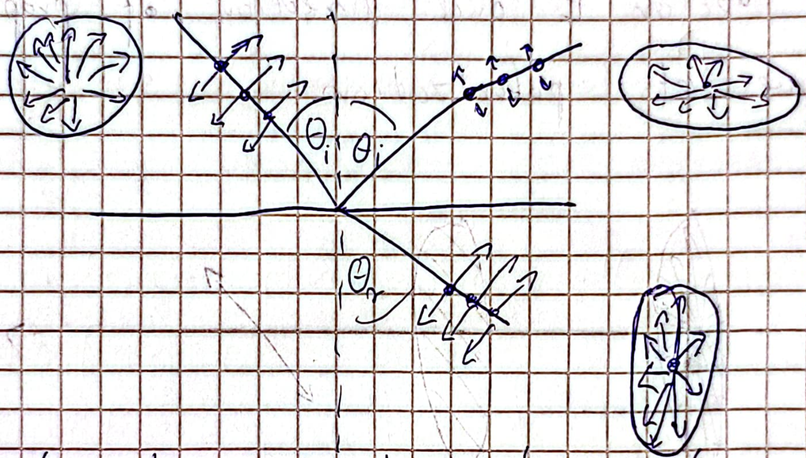
When light is reflected from a surface it can become partially or completely polarized.

The brewster angle is the angle of incidence at which the reflection coefficient for the polorization in plane of incidence becomes 0. This means that the

The refracted beam is partially polarized
The angle bet. reflected and refracted beams is 90° for Brewster angle.



partial polarization by reflection



Circular polarization is type of polarization in which the electric field vector of light rotates in a circular pattern as the light propagates.
It is a special case of elliptical polarization with the 2 components of electric field vector having equal amplitudes and phase difference of $\frac{\pi}{2}$

11.5.1
Double refraction - (birefrigence) occurres in crystals like quartz. When unpolarized light enters such material, it splits into 2 beams: the ordinary ray which follows normal refraction and extraordynary ray which behaves differently and has variable velocity and direction. This phenomenon is due

to the crystal's optical properties varying with direction. The crystal has an optic axis where both rays travel at the same velocity

Light scattering ~~re~~ - when light wave interacts with particles in a medium causing it to change direction and spread out. When light passes through a transparent medium it interacts with electrons in material, causing them to oscilate. This interaction leads to the emission of new waves, resulting in the scattering of light. In solid crystals the scattering is minimal because the osilating ~~partice~~ charges are closely bound and act cooperatively. In liquid and gases scattering is more significant. Scattered light is often partially polarized.

The sky is blue because of Rayleigh scattering, which is the scattering of shorter blue wavelengths in atmosphere. ~~This At sunset, the longer red wavelengths~~ Sunlight entering erths atmosphere interacts with ist molecules, them scatter the light, the amount of sattering depends on the wavelength of light. Shorter blue wavelengths are scattered more effectively than red, causing ~~sun~~ sky to appear blue.

Diffraction vs Interference

Diffraction: light waves bend or spread out when encountering obstacles or narrow openings. It creates patterns of intensity distribution

Interference: light waves combine and either reinforce or cancel out, forming patterns of bright and dark regions.

12. Dual character of light

Light is at the same time a wave and a stream of particles, called photons.

Evidence for both wave and colpuscular nature of light:

Wave:

light undergo phenomena called diffraction and interference which is proved by Young's double slit experiment - When light shone through ~~A~~ 2 closely separated slits we can observe pattern of dark and light fringes on screen behind slits, this indicate that light diffracts and interfere with itself.

colpuscular:

proved by Photoelectric effect - when light of a sufficiently high frequency shines on a metal surface, electrons are emitted. This emission cannot be explained by wave theory, insted it requires the concept of photons - discrete bundles of energy.

another experiment suporting colpuscular nature is Compton Effect

13. Thermal radiation - Wien's law, Stefan-Boltzmann law

Thermal radiation is radiation given of by a body due to it temperature.

Black body - ideal substance that absorbs and emits all frequencies of light

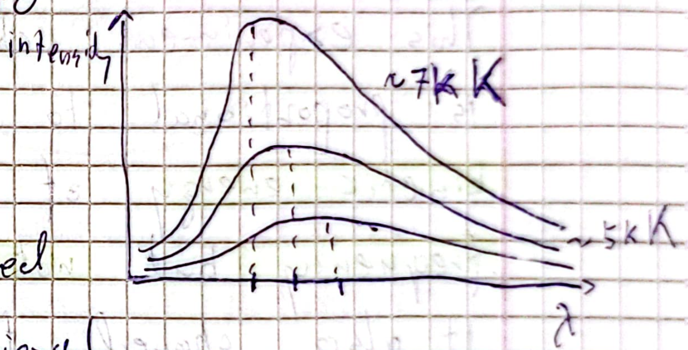
Wien's law

$$\lambda_{peak} = \frac{W}{T}$$ ← Wein's constant

Relation bet. temperature of black body and wavelength at which it emits the most light

As temperature increases the overall emitted energy increases and the peak of radiation move to shorter wavelengths

$$\boxed{\lambda_{peak} = \frac{W_k}{T}}$$



Stefan-Boltzmann law

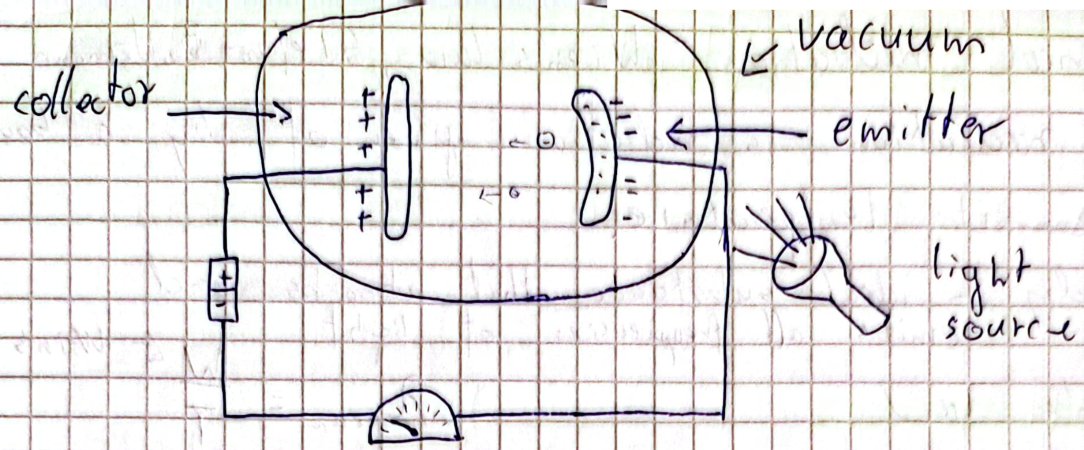
Total radiant heat energy emitted from a blackbody is proportional to the 4th power of its absolute temperature

$$\boxed{I(T) \sim T^4}$$

14. Photoelectric effect

effect where electrons are emitted from certain materials when light of a certain ~~frequencies~~ min. λ arrives at the material

The work function is the min amount of energy needed to break electron free from an atom.



$$\boxed{hf = E_{max} + A}$$

work function

kinetic energy of photoelectron

This experiment showed that num. of photoelectron is proportional to the light intensity and that kinetic energy of electrons depends on light frequency, but not on the intensity of radiation. It also showed that there is no current for frequencies smaller than f_0.
This results showed that light must behave like a particle.

15. Wave behavior of particles - de Broglie hypothesis

De Broglie proposed that particles such as electrons have wave-like properties.

$$\boxed{\lambda = \frac{h}{p}}$$

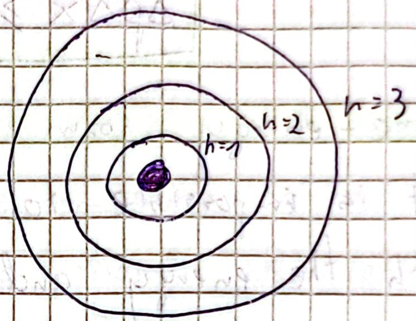
Plank's constant

linear momentum of particle

This hypothesis was proved experimentaly by showing that electrons diffract and interfere. To show this they used similar method to x-ray diffraction atomic structure which provides scattering surffaces at regular intervals and at atomic scale. The experiment showed that electrons interfare with each other and diffraction pattern ~~was~~ ~~visible~~ appears. This ~~meant that~~ was an evidence of dual nature of mater.

16. Structure of hydrogen atom - Bohr model and postulates

Bohr proposed a hydrogen atom model in which electrons circulates around the nucleus.



Postulates

1. Electrons can orbit nucleus only on stationary orbits, at fixed distances from nucleus, which correspond to strictly defined energies of electrons.
2. The angular momentum of electron on a stable orbit must be quantized, meaning only discrete values of angular momentum are possible $\boxed{L_n = m v_n r_n} = n\hbar$
3. The atom can emit or absorbe raddiation when electron goes from one of its orbit to another. The energy is emitted in form of photons and it is equal to difference in energy bet. those 2 states.

Against	For
- predicted wrong value for the orbital angular momentum in the ground state. - in reality electrons don't travel in circular orbits	- Bohr's model predicted the value of the Rydberg constant.

17. Heisenbergs' uncertainty principle - both forms

Defining limits of precision of measurements when dealing with very small objects.

- Position - momentum form

It is impossible to determine at the same time position and momentum of particle with unlimited precision:

$$\boxed{\Delta p \Delta x \geq \hbar = \frac{h}{2\pi}}$$

- time - energy form

It is impossible to determine at the same time both the energy and time coordinate of a particle with unlimited precision.

$$\boxed{\Delta E \Delta t \geq \hbar = \frac{h}{2\pi}}$$

Δ indicate a rande of uncertainty in measured values. It is a fundamental restriction imposed on us by nature.

If we try to reduce the uncertaity of one element the uncertaity of 2nd will increase.

We can measure either one element or the other precisely but cannot measure both simultaneously.

18. The Pauli exclusion principle

No 2 fermions may occupy the same quantum state

By applying this principle we can understand how electrons fill the shells and subshells in atom

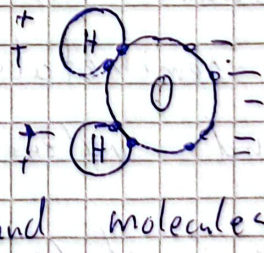
The Pauli exclusion principle plays a crucial role in determining the ~~electronic~~ structure of atoms and understanding the properties exhibitin by elements in the periodic table. It ensures the stability and organization of electron configurations, allowing for unique chemical behavior and properties of different ~~atoms~~ elements.

19. Bonds in solids

Ionic bonding occures bet. a metal and non-metal when a metal atom loses one or more e^- to non-metal. Thanks to that there is a strong ~~att~~ electrostatic attraction bet. positively charged ~~ions~~ cations and negatirly anions.

Covalent bonding is the sharing electrons bet. atoms. This type occure bet. 2 atoms of the same element or elements close in periodic table. This are strong bonds

Hydrogen bond occures when a hydrogen atom is bounded to highly electronegative atom (i.e. oxygen, nitrogen) and forms weak bond with another electronegative atom nearby. This is due to uneven distribution of ~~al~~ e^- in atom



Van der Walls forces are weak forces, which are the sum of the attractive and repulsive electrical forces bet. atoms and molecules. They differ from chemical bondings because they are ~~th~~ the effect of fluctuations in charge density of particles. For some moment there are more e^- on one site

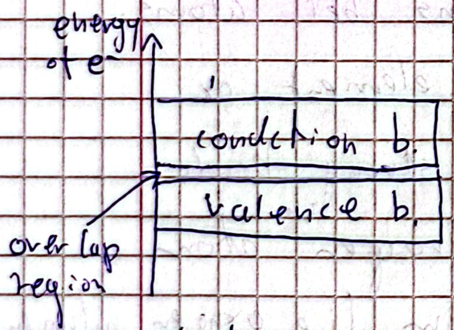
of particle [illegible]

20. Electrical conduction of solids, band theory

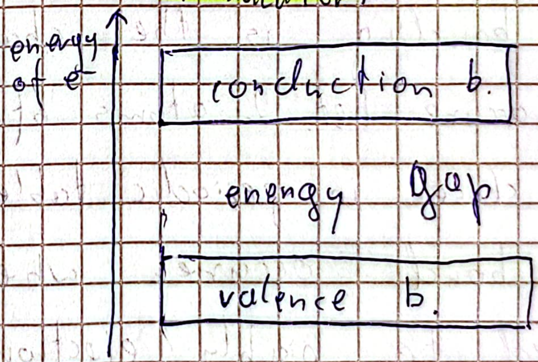
In solids all atoms are close to each other, so the neighboring atoms affect the energy levels of outermost orbit electrons. Those electrons are shared bet. the atoms and due to this phenomenon, the energies of the electrons will not be the same. The electrons in the same orbit exhibit diff. energy levels. The grouping of these energy levels is called energy band.

There are 3 energy bands, which are the most important: valence band, conduction band and the energy gap / forbidden band. The size of energy gap determines the electrical behavior of the solid.

conductors



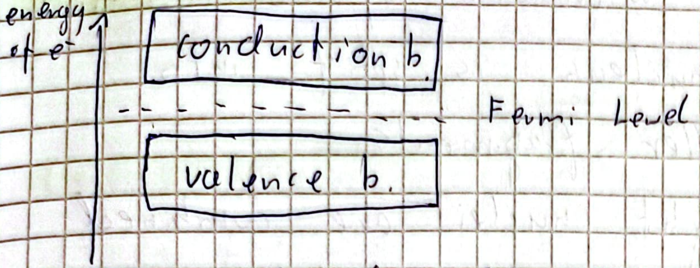
insulators



electrons in this partially filled ~~gap~~ band can respond to electric field because there are many nearby levels aviable.
In semimetals there is an overlap bet. conduction and valence band.

Semimetals have less carriers than metals and because of that are worse conductors.
The Fermi level represents the highest energy level occupied by e at absolute 0 temp.

21. Semiconductors



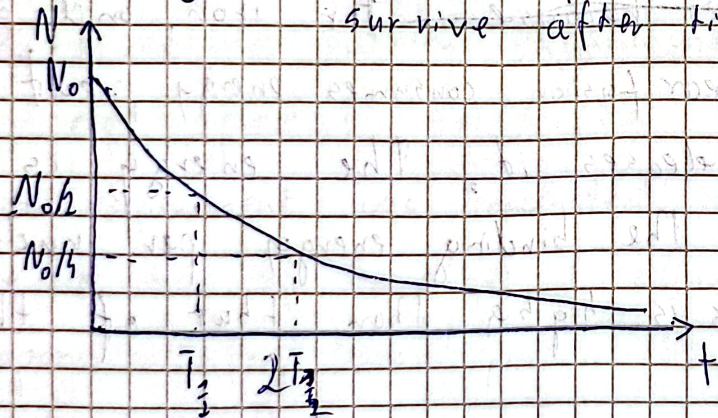
Fermi level plays a crucial role in determining the conductivity and the majority carriers in semiconductor.

Fermi Level determines the availability of electrons for conduction

22. Radioactive decay law and carbon dating

Radioactive decay is a random process; each decay is an independent event, and it is not possible to tell when any particular nucleus will decay. When a given nucleus decays, it transform into another nuclide, which may or may not be radioactive.

$N = N_0^{-\lambda t}$ — λ - decay constant
- number of ~~the~~ nuclei that will survive after time t



Time required for num. of nuclei to fall to ~~50%~~ 50% of its initial value is called half-life $T_{\frac{1}{2}}$

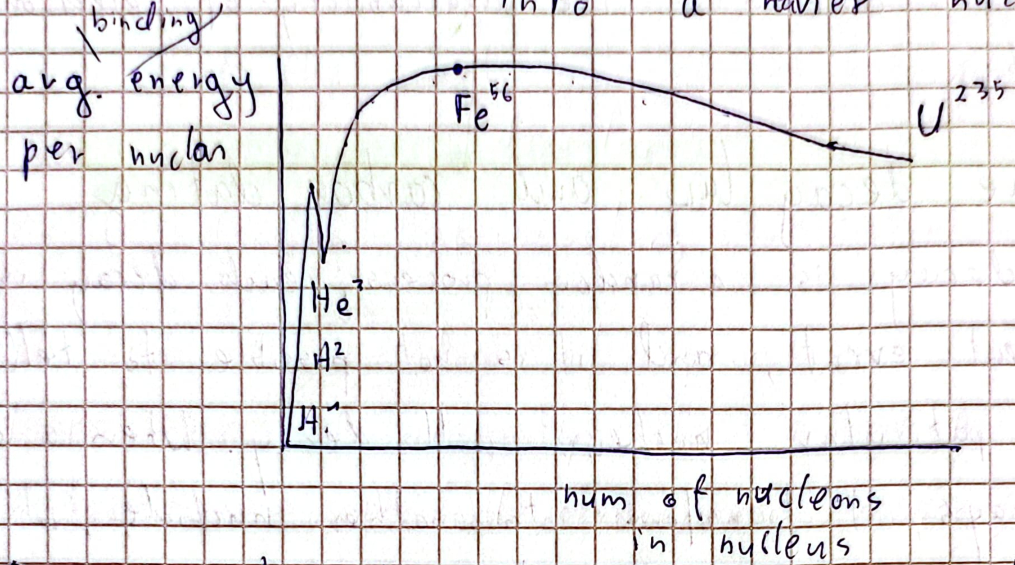
$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Carbon dating is used to determine the age of organic materials i.e. fossils. It relies on the decay of carbon-14 $^{14}_{6}C$ which has half-life of 5730 years.
A living organism is exchanging CO_2 with the environment so the ratio of the isotopes in it is the same as in atmosphere. As the organism dies the exchange stop and carbon starts to decay. By determining the amount of it in organism we can tell how old it is. It works very well for periods up to 50 000 years

23. Fission and fusion - when can they be exothermic

Nuclear Fission - hevy nucleus is split into 2 smaller fragments

Nuclear Fusion - 2 light nuclei are combined into a heavier nucleus.



For elements lighter than iron on the periodic table, nucler fussion releses energy while fission consumes it. ~~This is because~~ For iron and all heavier elements nuclear fusion consumes energy, but nuclear fission releases it. The energy is released because the binding energy per nucleon of resulting elements is higher than that of the orginal nucleus.

24. Expansion of the universe. Hubble's law, cosmic microwave background radiation

Hubble discovered that the universe is expanding and all galaxies appear to be moving away from us. This is not like objects moving through space, rather the space expanding itself.
Hubbles law states that the velocity of a galaxy is proportional to its distance from us, with

the proportionality constant known as Hubble constant.

$$\boxed{v = Hd}$$

Cosmic Microwave background radiation (CMB)

It is believed to be the remnants of the ~~hot and dense~~ early universe, which was extreamly hot and dense. The CMB represents the heat left from the Big Bang, when it was realised billions of years ago, it was hot and bright. The expansion of the universe has stretched space and with it, it streched the radiation, which is now in the microwave part of the electromagnetic spectrum. CMB has cooled over this time to present-day temp. - 2,73 K

25. Michelson-Morley experiment. Einstein's postulates of special relativity

This experiment was conducted in an attempt to detect the presence of the ether, a medium believed to be responsible for transmitting light waves. The experiment involved splitting a beam of light and reflecting it back and forth along diff. perpendicular paths to create interference pattern. The hypothesis was that the Earth's motion through the ether would case a slight difference in the time taken for the light to travel the 2 paths, resulting in an interference pattern. However, no interference pattern was obtained, indicating that speed of light was the same in all directions and didn't depend on Earth's motion in Ether.

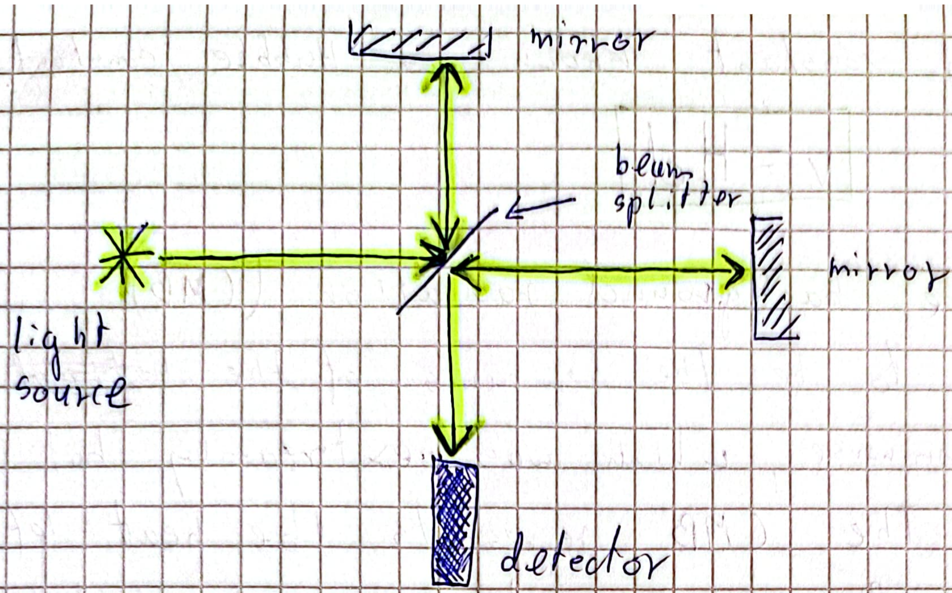


Fig. Michelson Interferometer.

Einstein's postulates of special relativity:

1. Principle of relativity: The laws of physics are the same for all observers in uniform motion.
   This means that the laws of physics are true regardless of an observer's motion. There is no privileged or preferred reference frame
2. Principle of the constancy of the speed of light: The speed of light in vacuum is the same in all inertial referance frames and is independent of the motion of the light source.
   This postulate is based on the results of the Michelson-Morley experiment and is a consequence of the 1st postulate, since if speed of light would be depended ~~on~~ on the source motion the laws of electrodynamic would depend on inertial frame of reference.

26. Time dilation and length contraction

Time dilation and length contraction are 2 effects predicted by the theory of relativity.

Time dilation means that time can appear to pass slower for objects that are moving fast relative to an observer. I.e. if you were on a spaceship traveling close to the speed of light, time would move slower for you, compared to someone on Earth.

Length contraction refer to an idea that objects can appear shorter when they are moving faster. I.e. if you were watching a fast-moving train, it would appear shorter to you than it actually is. This is because space itself becomes compressed in the direction of motion.

27. Why is it possible for a particle to tunnel through the potential barrier?

Quantum tunneling is a phenomenon where particles can pass through barriers that, according to classical physics, they shouldn't be able to cross. When a particle encounters a barrier, its wave-like nature allows it to extend into the barrier region. This means there is small chance the particle can tunnel through the barrier and appear on the other side, even if it doesn't have enough energy to overcome the barrier based on classical physics.

Practical applications of quantum tunneling include technologies like tunneling microscopy and tunneling transistors.

One of experimental confirmations of quantum tunneling is the scanning tunneling microscope (STM), which allows the visualization and manipulation of individual atoms on the surface of solids