Definitions

Quantum Tunneling: The transmission of a particle across a potential barrier that is larger than the total energy of the particle

Bragg Angle: Half of the scattering angle (angle between the unscattered beam and the scattered beam)

Spectral Emittance: Radiant energy emitted per unit wavelength interval of monochromatic radiation energy from a blackbody.

Resonant absorption: Absorption of a photon of an energy exactly equal to the difference of energies between the higher and lower energy state of an atom. This has the effect of causing the atom to be excited from the lower to the higher energy state.

Normalization constant: Constant associated with the wavefunction such that the total integral of its probability density across all space is equal to unity.

Fermi Energy of a metal: Energy of the highest quantum state of electrons in a metal at absolute zero. It is also the energy of the quantum state that has the probability 0.5 of being occupied by an electron.

Black body: A body that absorbs all electromagnetic radiation incident on it. It may be colored if the temperature is high enough to emit a significant amount of visible light.

Law of equipartition of energy: The amount of energy associated with each mode at equilibrium temperature is equal.

Compton Effect: Change in the wavelength of photons when they collide with electrons. Shows the particulate nature of light because this shift necessitates the transfer of energy in a collision.

Free electron theory: Assumes that conduction electrons in a metal are free to move throughout the volume of the sample, and that positive ions form a lattice. The interaction between electrons and ions are neglected.

Energy-band theory: Incorporates the contribution of the parent atoms, since the formation of bands is explained via the overlap of atomic orbitals.

Polarizing angle: Angle of incidence at which the reflected light is polarized in a direction perpendicular to the plane of incidence.

Proper Time: Time between two events which occur at the same position in the frame of reference in which the measurement is carried out.

Proper Length: Spatial separation between two events that occur at the same time in the frame of reference in which the measurement is carried out.

Numerical Aperture: A measure of an optical fibre's acceptance angle over which light rays entering the fibre will be guided along its core.

Frame of reference: Specifies the origin, spatial coordinates and start time so that other physical events can be described from it.

Inertial frame of reference: One in which Newton's first law of motion holds. It is a frame in which a body that is not acted on by a net external force continues to stay at rest.

Resolution criterion: Criterion for two distant objects to be considered as just resolved. Resolved if the first diffraction minimum of one images coincides with the central maximum of the other.

Attenuation Coefficient: Fractional decrease in optical intensity per unit distance.

Explain

Optics

How signals are transmitted in a step-index multimode fibre: In a step-index multimode fibre, the core has a relatively large diameter of 50um, and the refractive index changes abruptly at the cladding. The wide core allows signals to travel by several different paths or modes. Rays that cross the core more often travel further and therefore take longer to travel down the fibre. The output pulse is spread out in time compared to the input pulse. In a long fibre, separate pulses may overlap and errors and loss of information will result.

How signals are transmitted in a continuous index multimode fibre: In a continuous index multimode fibre, the refractive index of the glass varies continuously from a high value at the centre to a low value at the outside, making the core-cladding boundary indistinct. Signals taking the longer paths travel faster on average, and hence the arrival times for different modes are about the same, reducing dispersion.

Problems with optic fibre transmission: Spectral/ chromatic dispersion (pulse spreads due to different velocities for different wavelengths), Bending losses (sharp bends or imperfections at the core-cladding interface), Absorption/scattering losses (due to impurities), Coupling losses (due to poor joints).

Light propagation in an anisotropic medium: Ordinary waves travel with same speeds in all directions while extraordinary waves travel with different speeds in different directions. Along the optic axis, the two waves will have the same speed.

The advantages of optical fibers over copper wire: Thinner, less signal degradation, Better signal reception, Low power, Non-flammable (no electricity), Lightweight, Flexible.

Why you need goggles when swimming: In order to see things clearly, the eyes must focus light on the retina. Underwater, the shape and refractive index of the lenses in the eyes remain the same, but the index of the wave is greater than air. As a result, light is not refracted as much going into the eyes, and it focuses in a different place, blurring vision. When a diver wears goggles, the medium in front of his eyes is air, allowing for normal vision.

Relativity

Michelson-Morley experiment: Did not measure any change in the speed of light in relation to the relative motion of the postulated ether.

How does laser tube diameter affect the efficiency of the lasing process?
The bore size cannot be too large as this will impede efficient heat loss through collision with the container walls.

Postulates of special relativity: All laws of physics are the same in all inertial reference frames. The speed of light in vacuum is a constant in all frames.

Quantum

How an STM works: The air space between the tip of the STM and sample acts as a potential barrier. The tunneling probability (transmission coefficient) of electrons from the tip to surface decreases with increasing distance between the tip and surface. The current will vary as the STM moves over the surface, showing the topology of the sample surface.

The Ultraviolet Catastrophe: Rayleigh assumed that all possible frequency modes could radiate with equal probability, following the principle of equipartition of energy. Since the number of frequency modes per frequency interval continues to increase without limit with increasing frequency, Rayleigh predicted an ever-increasing amount of radiation of higher frequencies instead of the observed maximum.

Planck's Hypothesis and UVC resolution: Planck hypothesized that the oscillators do not have continuous energy levels, but discrete levels. Further, the probability of transition is reduced for transitions between levels that are further apart. this results in a smaller number of transitions and thereby less high energy waves emitted (small wavelength). Thus the intensity of low wavelength radiation is reduced instead of increasing to infinity in the classical case.

At a given temperature T, there is not enough thermal energy available to create and emit many large radiation quanta. More large energy quanta can be emitted when the temperature is raised.

Key assumptions in Planck's Law: Molecules only have discrete amounts of energy. Molecules emit and absorb energy in discrete amounts.

Why the zero-point energy is finite: Based on the uncertainty principle, if the energy is exactly zero, the uncertainty in its position is infinite. This is not possible as the particle in a harmonic oscillator is confined. Hence an energy of zero would violate the uncertainty principle.

Why a laser needs 3 energy levels: Stimulated emission will depopulate electrons from the metastable level to the lower energy level. To sustain a population inversion, there must be at least another higher short-lived energy level to replenish the electrons at the longer-lived meta-stable level.

The three laser energy levels: A lower ground state, a higher meta-stable state, an excited state of energy higher than the meta-stable state acting as a store of energy.

Conditions for the Quantum Hall Effect: High magnetic field, Low temperature

Conditions for a wavefunction: Wavefunction must be smooth. I.e. it must be continuous, and its derivative must be continuous.

How a Helium-Neon Laser works: A He-Ne laser contains 85% He and 15% Ne. A high potential difference is applied to the discharge tube, exciting the helium atoms from a ground state to a metastable state 20.61 eV above the ground state. Metastable state cannot radiatively return to the ground state as the transition is forbidden by selection rules. On collision, the He atoms transfer their energy to the Ne atoms, pumping the Ne atoms to a metastable state 20.66 eV above the ground state. There is a population inversion between the Ne metastable state and another lower-energy state, and stimulated emission causes lasing to occur. Spontaneous emission removes atoms from the Ne lower-energy state back to the ground state rapidly, sustaining the population inversion.

How does X-ray photoelectron spectroscopy work: High energy X-ray photons bombard the sample, releasing photoelectrons. Based on the electrons original energy level, the KE of the emitted photoelectrons will vary. The distribution of KEs are associated with the electron energy levels in the material. The electron binding energy may be determined by the following equation:
hf=E(binding)+KE
where KE is the energy at which an intensity peak occurs in the x-ray spectrum. This allows us to map out the energy level diagram in the given material.

Reason for Hall Effect: There is a Lorentz force acting on the electrons traveling in the material. The electrons experience a lateral force, accumulating at one side of the material. This builds up a potential difference until the further build-up of charges is prevented.

Features of quantum hall effect graph: Demonstrates quantization of resistance in units of h/e^2 divided by an integer.

Deductions from the potential energy curve between two atoms: Gradient of curve at $r=r_o$: modulus of elasticity. Deep, narrow trough: low coefficient of thermal expansion.

Why actual resolution is larger than calculated de Broglie wavelength?
Electrons may not be focused onto such as small spot as they will repel each other. Secondary electrons from neighboring atoms may be detected as the incident electrons can be scattered by the atom or penetrate into the depth of the sample.

Solid State

Why an intrinsic semiconductor has no Hall Voltage: An intrinsic semiconductor has equal numbers of positively and negatively charged carriers. Both of them will be deflected in the same direction. Thus, there will be no net charge on either side of the semiconductor, and no Hall voltage will be measured.

Zener Effect: With the application of a sufficiently high reverse bias voltage, a p-n junction will experience a rapid avalanche breakdown and conduct current in the reverse direction. Upon breakdown, the diode holds the voltage close to a constant value called the Zener voltage.

Reason for repulsive potential experienced in an ionic lattice: Overlapping of electron shells of neighboring atoms. There is a tendency for electrons from one atom to occupy states of the other atom. The Pauli Exclusion Principle prevents multiple occupancy and the electron distribution of atoms with closed shells can overlap only if electrons occupy the unoccupied higher energy states. Thus, the overlap increases the total energy and gives a repulsive contribution to the interaction.

How the Madelung constant (coefficient in front of net potential energy equation) arises: This term is due to two types of interactions, namely repulsive interactions between like charges and attractive interactions between unlike charges in the ionic compound lattice.