Note For Physics

May 14, 2020

Contents

Introduction

1. Learn Physics & Prepare for Exams

Simple

When learning physics, just keep it in your mind that physics equations are always **clean and simple**. So don't bother yourself.

Picture

Keypoint of learning physics is reading the **description of physics equation** and understanding it with **physical picture** kept in your mind.

Practice

Practice makes perfect. When you're preparing the exams, you can find missing point of knowledge from practice. Further more, you should understand these missing point and read the description of them on books.

Keep Calm

When you're in exam, just keep calm and repeat **readining the topic of questions**. You should confirm that you have obtained all of information given by examination questions.

2. SAT Requirements*

Questions cover topics emphasized in most high school courses. Because of course differences, most students will find that there are some questions on topics with which they are not familiar. You may not be able to complete all the questions in the time given, but it's not necessary to get every question correct to get a high score or even the highest score on the test.

Skills Covered in the Context of Physics

- Recalling and understanding of the major concepts of physics and the application of these physical principles to solve specific problems

  Fundamental Knowledge: remembering and understanding concepts or information (about 12%–20% of test)

Single-Concept Problems: applying a single physical relation or concept (about 48%–64% of test)

Multiple-Concept Problems: integrating of two or more physical relationships or concepts (about 20%–35% of test)

- Understanding simple algebraic, trigonometric, and graphical relationships and the concepts of ratio and proportion and the application of these to physics problems
- Application of laboratory skills in the context of the physics content outlined below

Important Things to Note on This Subject Test

- Numerical calculations are not emphasized and are limited to simple arithmetic.
- Questions predominantly use the metric system; pay attention to the units stated.
- You should assume that the direction of any current is the direction of flow of positive charge (conventional current).
- Calculator use is not permitted.

Recommended Preparation

- One-year introductory physics course on the college-preparatory level
- Laboratory experience—a significant factor in developing reasoning and problem-solving skills— even though this test can only measure lab skills in a limited way, such as data analysis

Chapter 1

Mechanics

1.1 Cener of Mass

The position of center of mass,

$$\boldsymbol{r}_c = \frac{m_1\boldsymbol{r}_1 + m_2\boldsymbol{r}_2 + ... + m_n\boldsymbol{r}_n}{m_1 + m_2 + ... + m_n}. \tag{1.1}$$

The integration form is,

$$\boldsymbol{r}_c = \frac{\int \rho(\boldsymbol{r})\boldsymbol{r} dr^3}{\int \rho(\boldsymbol{r}) dr^3}. \tag{1.2}$$

Calculate the time derivative of center of mass,

$$\boldsymbol{v}_c = \frac{m_1\boldsymbol{v}_1 + m_2\boldsymbol{v}_2 + ... + m_n\boldsymbol{v}_n}{M}. \tag{1.3}$$

In the absence of external force $F_{external} = 0$, we have the conservation of momentum,

$$M\boldsymbol{v}_c = m_1\boldsymbol{v}_1 + m_2\boldsymbol{v}_2 + ... + m_n\boldsymbol{v}_n = const. \tag{1.4}$$

And we can also calculate the acceleration of center of mass by calculating the time derivative of center of mass,

$$F_{external} = M\boldsymbol{a}_c. \tag{1.5}$$

1.2 Momentum

The definition of momentum is,

$$\boldsymbol{p} = m\boldsymbol{v} \tag{1.6}$$

Momentum is the time accumulation of Force.

$$\boldsymbol{F} = \frac{d\boldsymbol{p}}{dt}, \quad \boldsymbol{p} = \int \boldsymbol{F} dt \tag{1.7}$$

1.3 Kinematics

Scalar: average speed.

$$\text{average speed } = \frac{\text{total distance}}{time} \tag{1.8}$$

The definition of velocity and acceleration:

$$\boldsymbol{v}(t) = \frac{d\boldsymbol{s}}{dt} \tag{1.9}$$

$$\boldsymbol{a}(t) = \frac{d\boldsymbol{v}}{dt} \tag{1.10}$$

This two definitions can deduce the whole contents of Kinematics. So just keep it in your mind and understand it.
In case of constant acceleration with direction towards $\boldsymbol{x}$, we have 5 deduced formula:

$$\begin{cases} v_f - v_i = a_x t \\ \quad \Delta s = v_i t + \frac{1}{2} a_x t^2 \\ \quad \Delta s = v_f t - \frac{1}{2} a_x t^2 \\ 2a_x \Delta s = v_f^2 - v_i^2 \end{cases} \tag{1.11}$$

1.4 Dynamics

Newton's First law

- Moving objects keep moving.
- Resting objects keep resting.
- Law of Inertia: Objects naturally resist.
- The measure of inertia is mass.

Newton's Second law

$$\boldsymbol{F}_{net} = m\boldsymbol{a} \tag{1.12}$$

Foreces are vectors, measured in Newtons(N).

Newton's Thired law

Action-reaction pairs are equal in magnitude but opposites in direction, so $\boldsymbol{F}_{1-on-2} = -\boldsymbol{F}_{2-on-1}$.

Newton's law of gravitation

$$\boldsymbol{F} = -G\frac{m_1 m_2}{r^2}\hat{\boldsymbol{r}} \tag{1.13}$$

Friction

$$\begin{cases} F_{static} = \mu_s N \\ F_{kinetic} = \mu_k N \end{cases} \tag{1.14}$$

where N is the normal force.

1.5 Work, energy, and Power

It's difficult to give a precise definition of energy. Loosely speaking, energy is a quantity which gives an object or system the ability to accomplish something (what we will define as work).

Work-Enery Theorem

The **total work** done on an object–or the work done by the net force–is equal to the object's change in kinetic energy; this is known as the **Work-Enery Theorem**.

$$W_{total} = \Delta K \tag{1.15}$$

Kinetic energy, like work, is a scalar quantity.
The definition of **work** is,

$$W = \boldsymbol{F} \cdot d\boldsymbol{s} = F ds \sin\theta. \tag{1.16}$$

Use the definition of force $\boldsymbol{F} = m\boldsymbol{a} = md\boldsymbol{v}/dt$ and $d\boldsymbol{s} = \boldsymbol{v}dt$ and obtain,

$$\int_{initial}^{final} \boldsymbol{F} \cdot d\boldsymbol{s} = \int_i^f m\frac{d\boldsymbol{v}}{dt} \cdot \boldsymbol{v}dt = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \tag{1.17}$$

The energy an object possesses by virtue of its motion(simply just kinetic energy) is therefore defined as

$$K = \frac{1}{2}mv^2, \tag{1.18}$$

and is called **kinetic energy**.

Potential energy

Kinetic energy is the energy an object has by virtue of its motion, but potential energy is independent of motion and arises from the **object's position**. For example, a ball at the edge of a tabletop has energy that could be transformed into kinetic energy if it falls off. An arrow in an archer's pulled-back bow has energy that could be transformed into kinetic energy if the archer releases the arrow. Both of these examples illustrate the concept of **potential energy**(symbolized as U), the energy of an object or a system has by virtue of its position.
Because we have conservation of Mechanical energy which is the essential and basic theorem in physics,

$$E = K_{object} + U_{grav} \tag{1.19}$$

And take the change of energy, it will be 0.

$$\Delta E = \Delta K_{object} + \Delta U_{grav} = 0 \tag{1.20}$$

Then we can obtain below formula,

$$\Delta U_{grav} = -W_{bygravity} = -\Delta K_{object}. \tag{1.21}$$

Power

Simply put, **power** is the rate at which work is done (or energy is transfered, which is the same thing).

$$\text{Power} = \frac{\text{Work}}{\text{time}} \quad \text{in symbols} \rightarrow P = \frac{W}{t} \tag{1.22}$$

1.6 Circular Motion

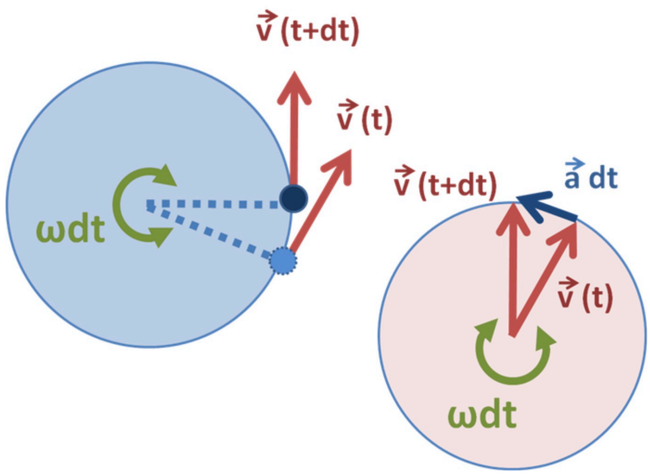

Figure 1.1: The velocity vectors at time t and time $t + dt$ are moved from the orbit on the left to new positions where their tails coincide, on the right. Because the velocity is fixed in magnitude at $v = \omega r$, the velocity vectors also sweep out a circular path at angular rate ω. As $dt \rightarrow 0$, the acceleration vector a becomes perpendicular to v, which means it points toward the center of the orbit in the circle on the left. Angle ωdt is the very small angle between the two velocities and tends to zero as $dt \rightarrow 0$.

For motion in a circle of radius r, the circumference of the circle is $C = 2\pi r$. The speed of the object travelling the circle is:

$$v = \frac{2\pi r}{T} = \omega r \tag{1.23}$$

In the case of uniform circular motion, ω will be constant.
The centripetal acceleration due to change in the direction is:

$$a = \frac{v^2}{r} = \omega^2 r \tag{1.24}$$

The **centripetal (ground frame)** or **centrifugal (moving frame)** force can also be found out using acceleration:

$$F_c = \dot{p} \overset{\dot{m}=0}{=} ma = \frac{mv^2}{r} \tag{1.25}$$

1.7 Simple Harmonic Motion

The motion of a particle moving along a straight line with an acceleration whose direction is always towards a fixed point on the line and whose magnitude is proportional to the distance from the fixed point is called simple harmonic motion (SHM)).
A harmonic oscillator is a system that, when displaced from its equilibrium position, experiences a restoring force F proportional to the displacement x:

$$\vec{F} = -k\vec{x}, \tag{1.26}$$

where k is a positive constant.

If F is the only force acting on the system, the system is called a **simple harmonic oscillator**, and it undergoes simple harmonic motion: sinusoidal oscillations about the equilibrium point, with a constant amplitude and a constant frequency (which does not depend on the amplitude).

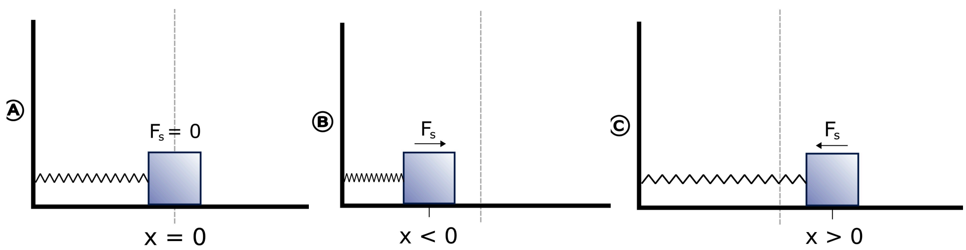

Figure 1.2: Spring–mass system in equilibrium (A), compressed (B) and stretched (C) states.

Let's use Newton's second law (Eq.(1.12)) and above Hooke's law(Eq.(1.26)). And we can obtain

$$F = ma = m\frac{\mathrm{d}^2x}{\mathrm{d}t^2} = m\ddot{x} = -kx. \tag{1.27}$$

Solving this differential equation, we find that the motion is described by the function

$$x(t) = A\cos(\omega t + \varphi), \tag{1.28}$$

where

$$\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T}. \tag{1.29}$$

The potential energy stored in a simple harmonic oscillator at position x is

$$U = \frac{1}{2}kx^2. \tag{1.30}$$

1.8 Newton's theory of Gravitation

Newton's law of universal gravitation states that every particle attracts every other particle in the universe with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.
The equation is the following:

$$\boldsymbol{F} = -G\frac{m_1 m_2}{r^2}\hat{\boldsymbol{r}} \tag{1.31}$$

Where F is the force, m_1 and m_2 are the masses of the objects interacting, r is the distance between the centers of the masses and G is the gravitational constant.

We can deduce the gravitational field $\boldsymbol{g}(\boldsymbol{r})$ as:

$$\boldsymbol{g}(\boldsymbol{r}) = -\frac{Gm_1}{\boldsymbol{r}^2}\hat{\boldsymbol{r}} \tag{1.32}$$

so that we can write:

$$\boldsymbol{F}(\boldsymbol{r}) = m\boldsymbol{g}(\boldsymbol{r}). \tag{1.33}$$

This formulation is dependent on the objects causing the field.

Gravitational potential energy is,

$$\Delta U(r) = -\boldsymbol{F}\cdot d\boldsymbol{r} \rightarrow U(r) = -\frac{Gm_1 m_2}{r}. \tag{1.34}$$

And we can obtain gravitaitonal potential by divided m_2,

$$\phi_g(r) = -\frac{Gm_1}{r}. \tag{1.35}$$

1.9 Collision

Because there're no external force during the collision. And we consider the elastic case,

$$\begin{cases} m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2' \\ \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 = \frac{1}{2}m_1 v_1'^2 + \frac{1}{2}m_2 v_2'^2 \end{cases} \tag{1.36}$$

$$\begin{cases} m_1(v_1 - v_1') = m_2(v_2' - v_2) \\ m_1(v_1^2 - v_1'^2) = m_2(v_2'^2 - v_2^2) \end{cases} \tag{1.37}$$

Use the equation of differece squares. We have,

$$v_1 + v_1' = v_2 + v_2'. \tag{1.38}$$

Then we can solve the equation,

$$\begin{cases} m_1(v_1 - v_1') = m_2(v_2' - v_2) \\ v_1 + v_1' = v_2 + v_2'. \end{cases} \tag{1.39}$$

And obtain,

$$\begin{cases} v_1 = \dfrac{2m_1v_1 + (m_2 - m_1)v_2}{m_1 + m_2} \\ v_2 = \dfrac{2m_2v_2 + (m_1 - m_2)v_1}{m_1 + m_2}. \end{cases} \tag{1.40}$$

In the case of $v_1 \neq 0$ and $v_2 = 0$,

$$\begin{cases} v_1 = & \dfrac{2m_1v_1}{m_1 + m_2} \\ v_2 = & \dfrac{m_1 - m_2}{m_1 + m_2}v_1. \end{cases} \tag{1.41}$$

1.10 Rotation of Rigid Body*

Rotation of particle on rotating body

$$\begin{cases} \boldsymbol{a}_{tan} = & \boldsymbol{\alpha} \times \boldsymbol{r} \\ \boldsymbol{a}_{cen} = & -\omega^2 \boldsymbol{r} \end{cases} \tag{1.42}$$

Motion with constant angular acceleration:

$$\begin{cases} \omega_f = \omega_i + \alpha t \\ \theta_f - \theta_i = \omega_i t + \dfrac{1}{2}\alpha t^2 \\ \theta_f - \theta_i = \dfrac{\omega_f^2 - \omega_i^2}{2\alpha} \end{cases} \tag{1.43}$$

Parallel-Axis Theorem

$$I = I_{CM} + Md^2, \tag{1.44}$$

where M is the total mass and d is the distance from **CM** axis.
Kinetic energy of Rotation

$$K_R = \frac{1}{2}I\omega^2 \tag{1.45}$$

1.10.1 Mass Density

Here is a very significant concept. We will introduce three main specific cases,

$$\begin{cases} \text{Linear Density: } \rho_L = \dfrac{M}{L} \text{ , and} \quad dm = \rho_L dL \\ \text{Area Density: } \rho_A = \dfrac{M}{A} \text{ , and} \quad dm = \rho_A dA \\ \text{Volum Density: } \rho_V = \dfrac{M}{V} \text{ , and} \quad dm = \rho_V dV \end{cases} \tag{1.46}$$

where L is the linear length(1 dimension) of objects.
where A is the Area(2 dimension) of objects.
where V is the Volum(3 dimension) of objects.

1.11 Dynamic of Rigid Body*

Angular momentum of particle

$$\boldsymbol{L} = m\boldsymbol{r} \times \boldsymbol{v} = \boldsymbol{r} \times \boldsymbol{p}, \tag{1.47}$$

where $\boldsymbol{r}$ is the displacement from axis to particle with momentum $\boldsymbol{p}$. **Torque** where θ is the angle between the force F and the radial line of length R.

$$\boldsymbol{\tau} = \boldsymbol{R} \times \boldsymbol{F} = RF \sin\theta. \tag{1.48}$$

Work done by torque

$$W = \int \boldsymbol{\tau} \cdot d\boldsymbol{\phi} \tag{1.49}$$

In the special case, work done by constant torque

$$W = \boldsymbol{\tau} \cdot \Delta\boldsymbol{\phi} \tag{1.50}$$

Power delivered by torque

$$P = \boldsymbol{\tau} \cdot \boldsymbol{\omega} \tag{1.51}$$

where ω is the angular velocity **Conservation of energy in rotational motion**

$$E = \frac{1}{2}I\omega^2 + U = const \tag{1.52}$$

In absence of external torque, we have above equation.
Dynamic equation of rotational momtion

$$\begin{cases} I\boldsymbol{\alpha} = \boldsymbol{\tau} \rightarrow \\ \dfrac{d\boldsymbol{L}}{dt} = \boldsymbol{\tau} \end{cases} \tag{1.53}$$

where I is the moment of inertial and α is the angular acceleration.

Angular momentum of rotation

$$\boldsymbol{L} = I\boldsymbol{\omega} \tag{1.54}$$

In 3-dimensional case, we obtain the complete form of angular momentum,

$$\boldsymbol{L} = I_x\boldsymbol{\omega}_x + I_y\boldsymbol{\omega}_y + I_y\boldsymbol{\omega}_y \tag{1.55}$$

In absence of angular acceleration $\boldsymbol{\alpha}$ or external torque(same meaning) $\boldsymbol{\tau} = 0$, we have **conservation of angular momentum**

$$\boldsymbol{L} = I\boldsymbol{\omega} = const. \tag{1.56}$$

Chapter 2

Electricity and Magnetism

2.1 SI Units

$$1A = 1C/s \tag{2.1}$$

2.2 Electric Field, Force & Potential

Electric field is caused by electric charge. There are two charged particles, electric field between them is

$$\boldsymbol{E} = k\frac{q_1}{r^2}\hat{\boldsymbol{r}}, \tag{2.2}$$

and the electric force between them can be obtained by Coulomb's law,

$$\boldsymbol{F} = k\frac{q_1 q_2}{r^2}\hat{\boldsymbol{r}}. \tag{2.3}$$

Electric Forec put on the charged particle is,

$$\boldsymbol{F} = q\boldsymbol{E}. \tag{2.4}$$

And we can calculate the electric field from the gradient of potential,

$$\boldsymbol{E} = -\frac{dU}{d\boldsymbol{r}}. \tag{2.5}$$

As we all know, the change of potential energy is equal to the negative work done by field,

$$\Delta U_E = -\Delta W_E, \text{as well sa } \ \Delta U_G = -\Delta W_G \tag{2.6}$$

And the U is electric potential energy.
For more details, we have

$$\Delta U = -W = -\int \boldsymbol{F} \cdot d\boldsymbol{s} = -\int \boldsymbol{E} \cdot d\boldsymbol{s} \tag{2.7}$$

And another keypoint,

$$\Delta U = q\Delta\phi, \tag{2.8}$$

where ϕ is the potential.

2.3 Capacitance

The definition of capacitance is,

$$C = \frac{Q}{V}. \tag{2.9}$$

In special case, we have

$$\begin{cases} C = \dfrac{\epsilon_0 A}{d} \quad , & \text{for two sheets with distance} d. \\ C = 4\pi\epsilon_0 R \quad , & \text{for spheer with radias} R. \end{cases} \tag{2.10}$$

Use the equation of (2.8) to obtain the ennergy conserved in the capacitance,

$$dU = qd\phi = qdV = CVdV \rightarrow U = \frac{1}{2}CV^2 \tag{2.11}$$

2.4 Circuit Elements

An electric current is a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. Generally, electric current can be represented as the rate at which charge flows through a given surface as:

$$I = \frac{dQ}{dt} \tag{2.12}$$

Ohm's law

$$I = \frac{\Delta\phi}{R} = \frac{V}{R} \tag{2.13}$$

Energy and Power

One particle with charge q go from the one of terminal to the other terminal of battery with voltage V. It will change the potential energy by battery,

$$\Delta U = qV. \tag{2.14}$$

This process cost time t. And we can find power of this battery,

$$P = \frac{qV}{t} = IV = I^2 R = \frac{V^2}{R}. \tag{2.15}$$

And we also know the change of energy is

$$P\Delta t = \Delta U \tag{2.16}$$

For our wire of area A and length l, it is customary to define the resistance R of the wire as

$$R = \rho\frac{l}{A}, \tag{2.17}$$

where ρ is the resistivity of materials.

It's convenient to write down the precise form of ρ,

$$\rho = \frac{m_e}{e^2 n_e \tau} \tag{2.18}$$

where m_e is the mass of electron, n_e is number density of electrons and τ is the average collision time.
In the whole circuit, we have **electromotive force**(emf) will equal to the whole change of potential

$$\mathcal{E} + \Delta V = 0 \tag{2.19}$$

Ammeters & Voltmeters

Ammeters and voltmeters are used to monitor electric circuits.

Ammeters measure the current flowing in a circuit. They have a low resistance, which keeps them from interfering with the circuit. This is necessary because they are hooked in a series with a circuit being measured, and a large resistance would decrease the current being measured with the meter.
Voltmeters are used to measure voltage changes in a circuit. They have a high resistance and are used in parallel with the circuit being measured. The high resistance in the voltmeter causes all but the tiniest fraction of current to pass through the circuit being measured, which prevents the voltmeter from interfering with the circuit.

2.5 Direct Current Circuit & RC Circuit

Problem-Solving Techniques:
Kirchhoff's Rules and Multiloop Circuits.

Electromotive Force(emf)=$\mathcal{E}$ with unit: voltage or energy per unit charge, is provided by a source.

Kirchhoff's voltage rule

The sum of emfs and potential changes across resistors around any closed loop in a circuit must equal zero.

$$\mathcal{E} + \Delta V = 0 \tag{2.20}$$

Sign conventions
When traversing a source of emf in the forward direction ($-$ to $+$ terminal), the voltage is positive, ($\mathcal{E}$); in the reverse direction ($+$ to $-$ terminal), the voltage is negative ($-\mathcal{E}$). Traversing a resistor in the direction of the current provides a voltage drop (negative, $-IR$); doing so in the direction opposite to the current provides a voltage increase (positive, $+IR$).

Kirchhoff's current rule

The total current flowing into any junction must equal the total current flowing out of the junction:

$$\sum I_{in} = \sum I_{out} \tag{2.21}$$

2.6 Magnetism

Permeability constant

$$\mu_0 = 4\pi \times 10^{-7} N \cdot s^2/C^2 \approx 1.26 \times 10^{-6} N \cdot s^2/C^2 \tag{2.22}$$

SI unit of magnetic field

$$1\ tesla = 1\ T = 1N/(C \cdot m/s) \tag{2.23}$$

Biot–Savart Law

Contribution to magnetic field: where $\boldsymbol{r}$ is the vector from the current element $I d\boldsymbol{s}$ to the point P.

$$d\boldsymbol{B} = \frac{\mu_0}{4\pi} \frac{I d\boldsymbol{s} \times \boldsymbol{r}}{r^3} \tag{2.24}$$

If the current and P are in the same plane, then

$$B = \int dB = \int \frac{\mu_0}{4\pi} \frac{I ds \times r \sin\theta}{r^3} \tag{2.25}$$

Force exerted by magnetic field on moving charge

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B} = I\boldsymbol{l} \times \boldsymbol{B} \tag{2.26}$$

Add the electric force into the formula, we obtain the **Lorentz Force**

$$\boldsymbol{F} = q\boldsymbol{E} + q\boldsymbol{v} \times \boldsymbol{B} \tag{2.27}$$

Amper's Law

$$\oint \boldsymbol{B} \cdot d\boldsymbol{s} = \mu_0 I \tag{2.28}$$

where, for cylindrical symmetry,

$$\oint B_{//} ds = \begin{cases} \boldsymbol{B} \times 2\pi r \\ \boldsymbol{B} \times l \end{cases} \tag{2.29}$$

$$\boldsymbol{F}_{12} = \frac{\mu_0}{4\pi} \iint \frac{I_1 d\boldsymbol{r}_1 \times I_2 d\boldsymbol{r}_2}{(\boldsymbol{r}_1 - \boldsymbol{r}_2)^2} \tag{2.30}$$

Gauss Law for Magnetism

For closed surface,

$$\oint \boldsymbol{B} \cdot d\boldsymbol{s} = 0 \tag{2.31}$$

Right-Hand Rule

Review notes.

2.7 Electromagnetic Induction

Motional emf

$$\mathcal{E}_m = \boldsymbol{l} \cdot \boldsymbol{v} \times \boldsymbol{B} \tag{2.32}$$

Electromotive Flux

Here we introduce the magnetic flux. Magnetic flux (often denoted Φ or Φ_B) through a surface is the surface integral of the normal component of the magnetic field $\boldsymbol{B}$ passing through that surface.
For simple case, we have that the magnetic flux through an area A is equal to the product of A and the magnetic field perpendicular to it.

$$\Phi_B = \boldsymbol{B} \cdot \boldsymbol{A} = BA\cos\theta \tag{2.33}$$

Faraday's law of electromagnetic induction

$$\mathcal{E}_{avg} = -\frac{\Delta\Phi_B}{\Delta t} \tag{2.34}$$

Notice the negative sign "$-$" here which explain the core contents of Lenz's law.

Lenz's Law

Lenz's law states that the direction of the current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes the initial changing magnetic field. Lenz's law is shown by the negative sign in Faraday's law of induction.
Let's figure out the logic here.

$$\begin{array}{ccc} -d\Phi_B/dt \rightarrow & \boldsymbol{E}_{induced} \rightarrow & \mathcal{E}_{emf} = -\Delta\phi = \int \boldsymbol{E} \cdot d\boldsymbol{s} \\ \uparrow & & \downarrow \\ \boldsymbol{B} & \longleftarrow & I \end{array}$$

Chapter 3

Waves

3.1 New variables

New Variables	**Units**
λ=wavelength	m(meters)
c=speed of light	$3 \times 10^8 m/s$ (meters per second)

3.2 Traveling waves

The speed of wave is

$$c = f\lambda \tag{3.1}$$

where f is the frequency which means the number of revolution per unit time, and λ is the wavelength which means the distance that shape of wave traveled per unit revolution.

3.3 Superposition

The **superposition principle**, also known as superposition property, states that, for all linear systems, the net response caused by two or more stimuli is the sum of the responses that would have been caused by each stimulus individually. So that if input x_1 produces response $F(x_1)$ and input x_2 produces response $F(x_2)$ then input $(x_1 + x_2)$ produces response $(F(x_1) + F(x_2))$.

The homogeneity and additivity properties together are called Superposition. A linear function is one that satisfies the properties of superposition. It is defined as

$$F(x_1 + x_2) = F(x_1) + F(x_2) \qquad \text{Additivity} \tag{3.2}$$

$$F(ax) = aF(x) \qquad \text{Homogeneity} \tag{3.3}$$

for scalar a.

Figure 3.1: Superposition of almost plane waves (diagonal lines) from a distant source and waves from the wake of the ducks. Linearity holds only approximately in water and only for waves with small amplitudes relative to their wavelengths.

3.4 Mechanical waves

Mechanical wave is a wave that is an oscillation of matter, and therefore transfers energy through a medium. A mechanical wave requires an initial energy input. Once this initial energy is added, the wave travels through the medium until all its energy is transferred.

Figure 3.2: Ripple in water is a mechanical wave.

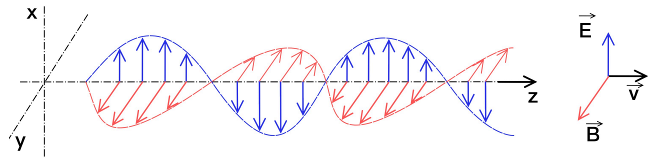

Figure 3.3: The electric field (blue arrows) oscillates in the x-direction, and the orthogonal magnetic field (red arrows) oscillates in phase with the electric field, but in the y-direction.

3.5 Electromagnetic waves

Electromagnetic radiation (EM radiation or EMR) refers to the waves (or their quanta, photons) of the electromagnetic field, propagating (radiating) through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays (see Fig.(3.4)).
Classically, electromagnetic radiation consists of electromagnetic waves, which

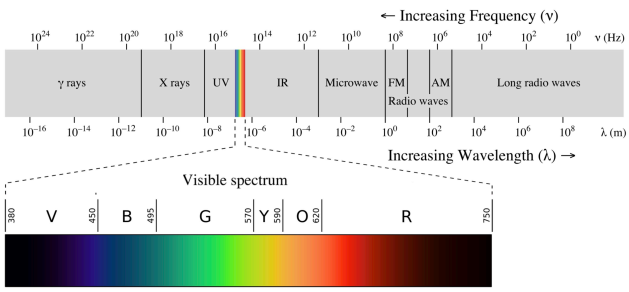

Figure 3.4: Electromagnetic spectrum with visible light highlighted.

are synchronized oscillations of **electric and magnetic fields** that propagate at the speed of light, which, in a vacuum, is commonly denoted c.

3.6 Transverse wave & Longitudinal wave

Transverse wave is a moving wave that consists of oscillations occurring perpendicular (right angled) to the direction of energy transfer (or the propagation of the wave).

Longitudinal wave is wave in which the displacement of the medium is in the same direction as, or the opposite direction to, the direction of propagation of the wave.

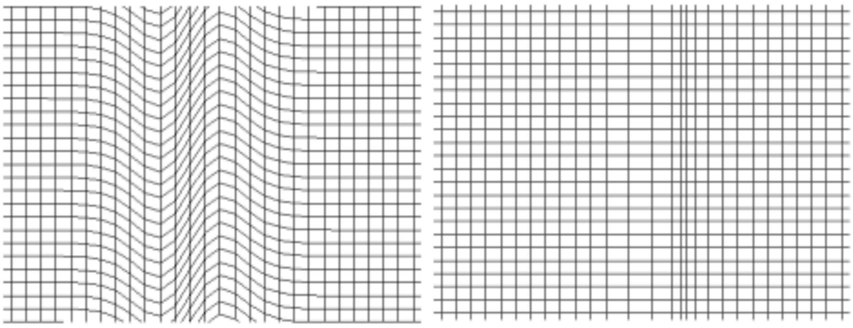

Figure 3.5: (LHS.)Transverse wave.(RHS.)Longitudinal wave.

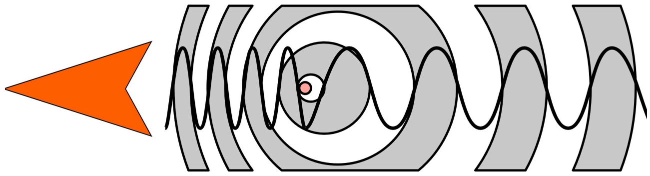

Figure 3.6: Change of wavelength caused by motion of the source.

3.7 Doppler effect

Here we make stipulative convention that c is the speed of wave.
Source moves toward to the observer with velocity v_s while observer rests (see Fig.(3.6)).

$$f' = \frac{f}{1 - v_s/c} \tag{3.4}$$

Observer moves toward to the source with velocity v_o while source rests.

$$f' = f\left(1 + \frac{v_o}{c}\right) \tag{3.5}$$

3.8 Standing wave

A standing wave is a wave which oscillates in time but whose peak amplitude profile does not move in space. The peak amplitude of the wave oscillations at any point in space is constant with time, and the oscillations at different points throughout the wave are in phase. The locations at which the amplitude is **minimum** are called **nodes**, and the locations where the amplitude is **maximum** are called **antinodes**.

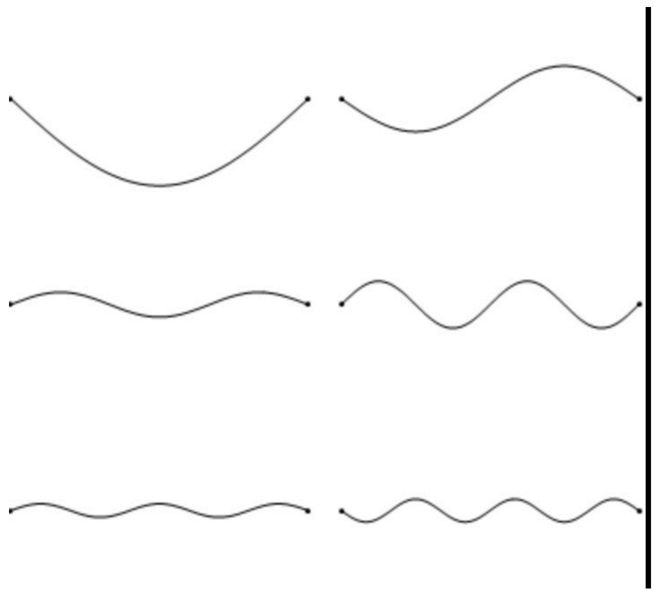

Figure 3.7: Standing waves in a string – the fundamental mode and the first 5 overtones.

Chapter 4

Optics

4.1 New variables

New Variables	**Units**
n=index of refraction	No units
θ_c=critical angle	Degrees
R=radius of curvature	m (meters)
f=focal distance	m (meters)
d_o=object distance	m (meters)
d_i=image distance	m (meters)
h_o=object height	m (meters)
h_i=image height	m (meters)
M=magnification	No units

4.2 Law of Reflection

Statements: In the case of reflection and refraction, there will be change in wavelength and speed while frequency never change.
The angle that the **incident beam** makes with the normal is called the **angle of incidence**, or θ_1. The angle that the **reflected beam** makes with the normal is called the **angle of reflection**, θ_1'. And the **transmitted beam** makes with the normal is called the **angle of refraction**, θ_2. The incident, reflected, and transmitted beams of light all lie in the same plane.

$$\theta_1 = \theta_1' \tag{4.1}$$

4.3 Snell's Law

Refraction is the phenomenon of a wave changing its speed. Mathematically, this means that the size of the phase velocity changes. Typically, refraction occurs when a wave passes from one medium into another. The amount by which a wave is refracted by a material is given by the refractive index of the

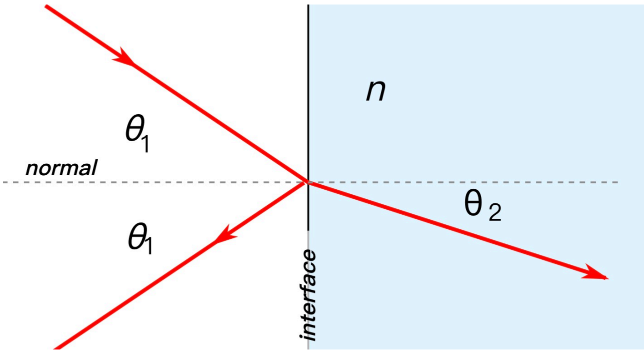

Figure 4.1: Geometry of reflection and refraction of light rays.

material. The directions of incidence and refraction are related to the refractive indices of the two materials by **Snell's law**.
The equation of Snell's law that relates θ_1 and θ_2 involves the index of refraction of the incident medium(n_1) and the index of refraction of the refracting medium (n_2).

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{4.2}$$

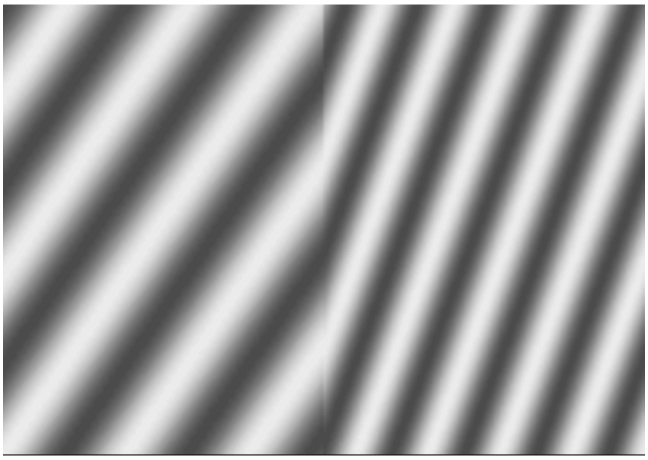

Figure 4.2: Sinusoidal traveling plane wave entering a region of lower wave velocity at an angle, illustrating the **decrease in wavelength** and change of direction (refraction) that results.

Note that wave velocity in the incident medium(n_1) is,

$$v_1 = \frac{c}{n_1}, \tag{4.3}$$

and wave velocity in the refractive medium(n_2) is

$$v_2 = \frac{c}{n_2}. \tag{4.4}$$

So the wavelength decreased by the medium (frequency of wave never change when cross the different medium) is just,

$$\begin{cases} \lambda_1' = \dfrac{v_1}{f} = \dfrac{c}{n_1 f} = \dfrac{\lambda}{n_1} \\ \lambda_2' = \dfrac{v_2}{f} = \dfrac{c}{n_2 f} = \dfrac{\lambda}{n_2}. \end{cases} \tag{4.5}$$

4.4 Total Internal Reflection

Total internal reflection occurs when

- $n_1 > n_2$
- $\theta_1 > \theta_c$, where $\theta_c = \sin^{-1}(n_2/n_1)$

4.5 Interference and Diffraction

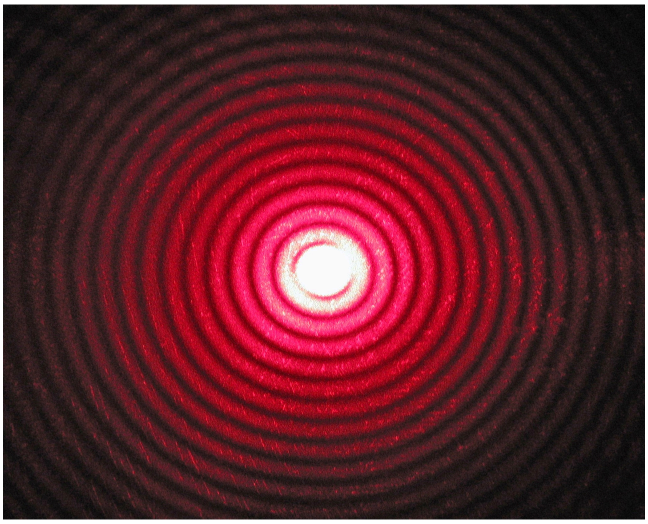

Figure 4.3: Diffraction pattern of red laser beam made on a plate after passing through a small circular aperture in another plate.

Single-slit Diffraction

Statements:
A long slit of infinitesimal width which is illuminated by light diffracts the light into a series of circular waves and the wavefront which emerges from the slit is a cylindrical wave of uniform intensity.

A slit which is wider than a wavelength produces interference effects in the space downstream of the slit. These can be explained by assuming that the slit behaves as though it has a large number of point sources spaced evenly across the width of the slit. The analysis of this system is simplified if we consider

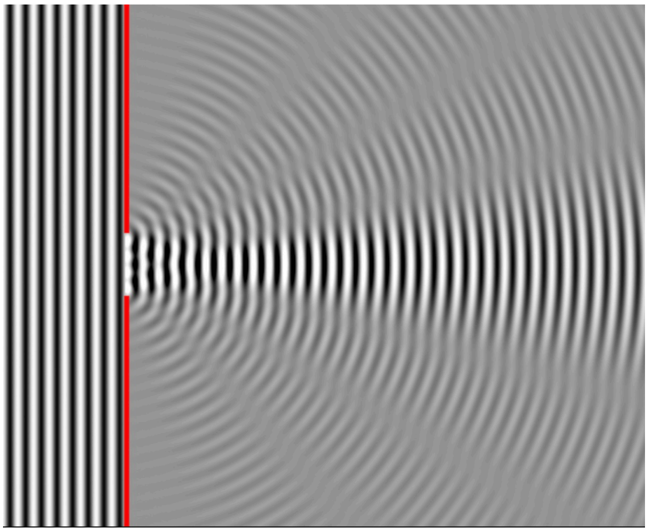

Figure 4.4: Numerical approximation of diffraction pattern from a slit of width four wavelengths with an incident plane wave. The main central beam, nulls, and phase reversals are apparent.

light of a single wavelength (because light consist of the electromagnetic wave with different wavelength in general).
We can find the angle at which a first minimum is obtained in the diffracted light by the following reasoning. The light from a source located at the top edge of the slit interferes destructively with a source located at the middle of the slit, when the path difference between them is equal to $\lambda/2$(review your notes and I have taught this picture). Similarly, the source just below the top of the slit will interfere destructively with the source located just below the middle of the slit at the same angle. We can continue this reasoning along the entire height of the slit to conclude that the condition for destructive interference for the entire slit is the same as the condition for destructive interference between two narrow slits a distance apart that is half the width of the slit. The path difference is approximately $d\sin\theta/2$ so that the minimum intensity occurs at an angle θ_{min} given by

$$\frac{d\sin\theta}{2} = \frac{\lambda}{2} \tag{4.6}$$

where

- d is the width of the slit,
- θ_{min} is the angle of incidence at which the minimum intensity occurs, and
- λ is the wavelength of the light

A similar argument can be used to show that if we imagine the slit to be divided into four, six, eight parts, etc., minima are obtained at angles θn given by

$$d\sin\theta_n = n\lambda \tag{4.7}$$

where

- n is an integer other than zero.

Double-slit Interference

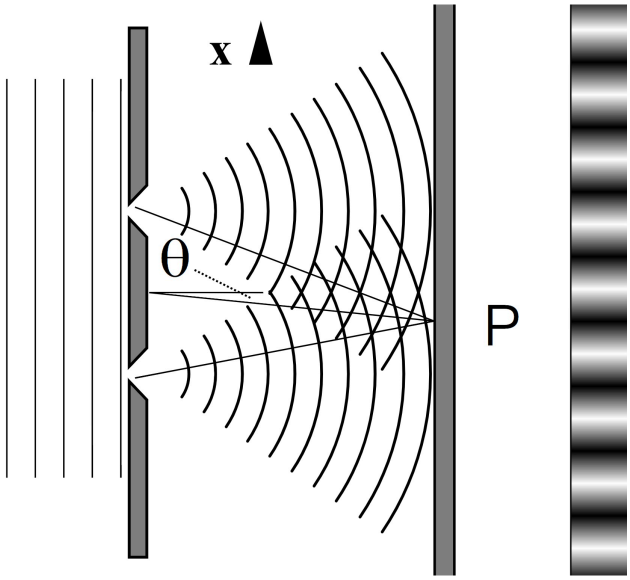

Figure 4.5: Two slits are illuminated by a plane wave.

Extented Contents:
Much of the behaviour of light can be modelled using classical wave theory. The Huygens–Fresnel principle is one such model; *it states that each point on a wavefront generates a secondary wavelet, and that the disturbance at any subsequent point can be found by summing the contributions of the individual wavelets at that point.* [1] This superposition needs to take into account the phase as well as the amplitude of the individual wavelets. It should be noted that only the intensity of a light field can be measured—this is proportional to the square of the amplitude.
Statements:
In the double-slit experiment, the two slits are illuminated by a single laser beam. If the width of the slits is small enough (less than the wavelength of the laser light), the slits diffract the light into cylindrical waves. These two cylindrical wavefronts are superimposed, and the amplitude, and therefore the intensity, at any point in the combined wavefronts depends on both the magnitude and the phase of the two wavefronts. The difference in phase between the two waves is determined by the difference in the distance travelled by the two waves.
If the viewing distance is large compared with the separation of the slits (the far field), the phase difference can be found using the geometry shown in the figure below right. The path difference between two waves travelling at an angle θ is given by:

$$d \sin\theta = n\lambda \tag{4.8}$$

[1] In fact, we have used this principle in the previous section.

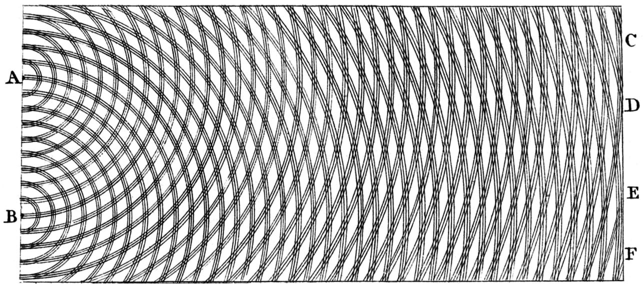

Figure 4.6: Thomas Young's sketch of two-slit interference based on observations of water waves.

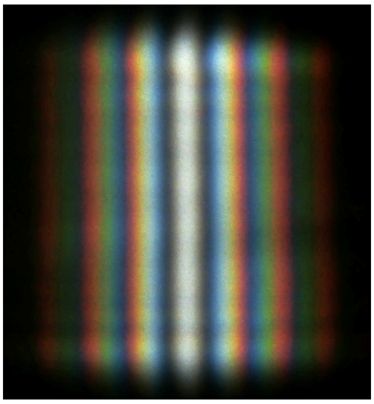

Figure 4.7: Photo of the double-slit interference of sunlight.

Dispersion of light

4.6 Mirrors

The fastest and easiest way to get information about an image is to use two equations and some simple conventions. The first equation,

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \tag{4.9}$$

where s_o is the distance between the object and the lens(or mirror), s_i is the distance between the image and the lens(mirror), f is the focal length of lens(mirror) which is the distance between the focal point and the lens(mirror). And we have the **magnification formula**,

$$M = -\frac{s_i}{s_o} \tag{4.10}$$

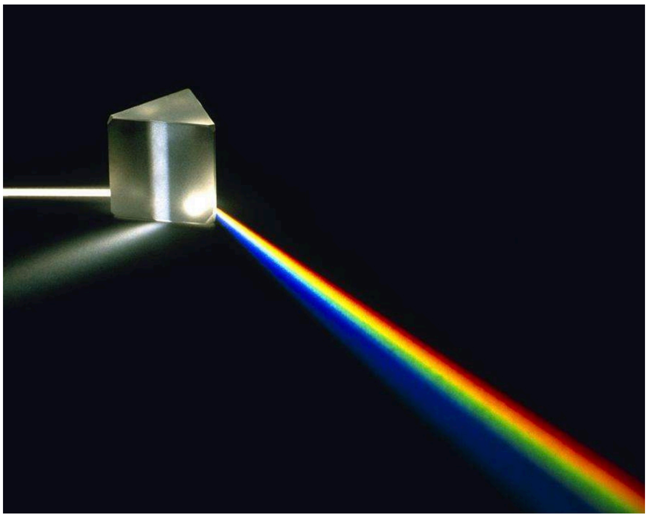

Figure 4.8: Dispersion of sunlight.

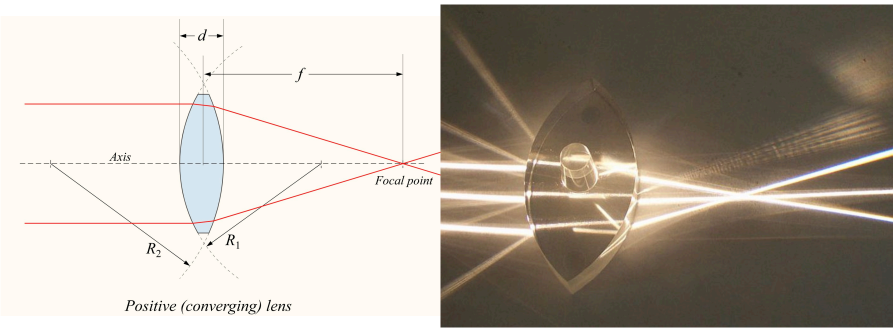

Figure 4.9: Light path cross through the **convex lens**.

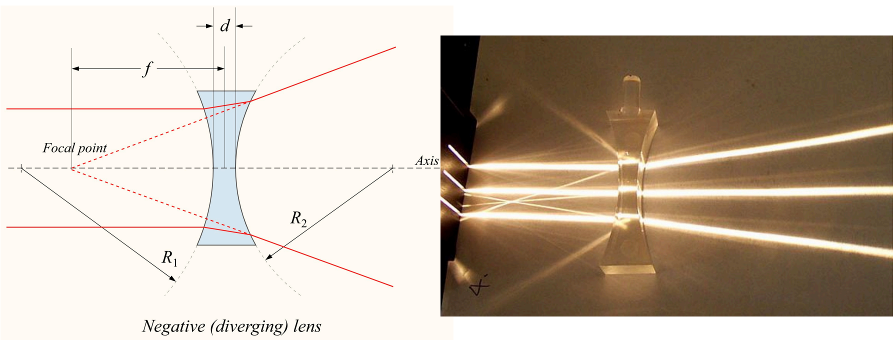

Figure 4.10: Light path cross through the **concave lens**.

Chapter 5

Thermodynamics

5.1 New variables

New Variables	**Units**
T=temperature	kelvin
E_{th}=thermal energy	j(joules)
M=molar mass	kg/mol (kilograms per mole)
α= coefficient of linear expansion	$1/K$ or $1/°C$ or $°C^{-1}$
P=pressure	Pa(pascals)
V=volume	m^3 (meters cubed)
n=number of moles	mol (moles)
R=universal gas constant	$8.31 J/mol \cdot K$
Q=heat	J(joules)
k=thermal conductivity	$W/m \cdot K$ (watts per meter $\cdot$ kelvin)
c=specific heat capacity	$J/kg \cdot K$ (joules per kilogram $\cdot$ kelvin)
L=latent heat	J/kg (joules per kilogram)

5.2 Laws of Thermaldynamics

Thermodynamics is the branch of physics that deals with the conversion of one form of energy into another, especially the conversion of heat into other forms of energy. These conversions are governed by the three fundamental laws of thermodynamics. As we will see, the first of these is a general statement of the thermodynamic equilibrium with the **same temperature**,the second of these is essentially a general statement of the **Law of Conservation of Energy**, and the third is a statement about the maximum efficiency attainable in the conversion of heat into work.

Zeroth laws of Thermaldynamics

Statements: *If two systems(A & B) are in thermal equilibrium with a third system(C), then they are in thermal equilibrium with each other.*

$$T_A = T_B = T_C \tag{5.1}$$

That means they will have the **same temperature** when being thermal equilibrium.

First laws of Thermaldynamics

$$\Delta E = Q - W \tag{5.2}$$

where ΔE is the change of internal energy of the **system**, Q is the heat added into the **system** and W is the work done by the **system**. In the case of gas system, we can figure out something significant here. Note the sign conventions

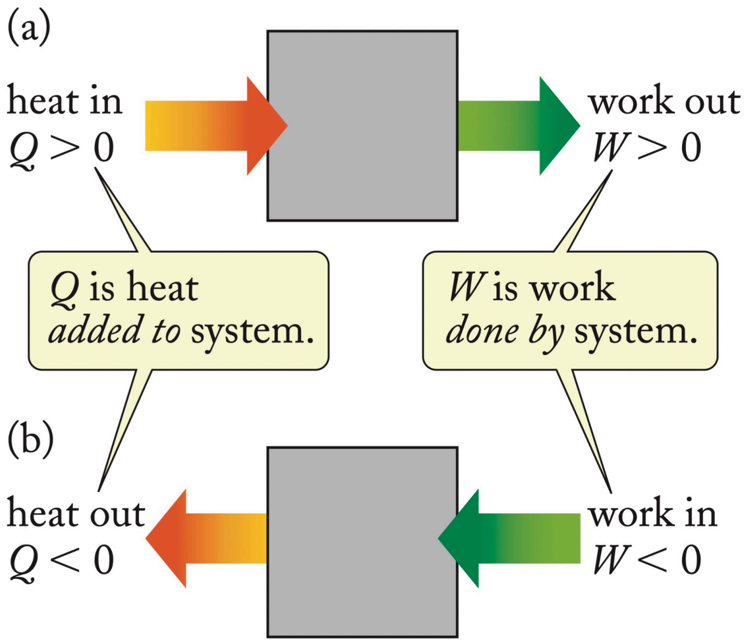

Figure 5.1: (a) If the system receives heat from its surroundings and performs work on its surroundings, Q is positive and W is positive. (b) If the system delivers heat to its surroundings and the surroundings perform work on the system, Q is negative and $W$is negative.

in this Eq.(5.2)(getting **picture** here): Q is positive if we add heat to the gas and negative if we remove heat; W is positive if the gas does work on us and negative if we do work on the gas (see Fig.5.1).

Second laws of Thermaldynamics

The second law of thermodynamics states that the total entropy(chaos or disorder) of an isolated system can never decrease over time. *The total entropy can remain constant in ideal cases where the system is in a steady state (equilibrium), or is undergoing a reversible process.* In all spontaneous processes, the total entropy increases and the process is irreversible. The increase in entropy accounts for the irreversibility of natural processes, and the asymmetry between future and past.

$$dS = \frac{dQ}{T} \tag{5.3}$$

Eq.(5.3) is the definition of entropy which means the heat transfered per unit kelvin. In the reversible case, we consider that two states A and B of a system, the entropy difference ΔS between them is defined as the sum of the heat exchanges divided by the temperature for some reversible process that takes the system from the initial state A to the final state B:

$$\Delta S = \int_A^B \frac{dQ}{T} \quad \text{(reversible process).} \tag{5.4}$$

For more details, see *example 6 and solution of Physics vol1. Page 679.*

Heat Engine Efficiency

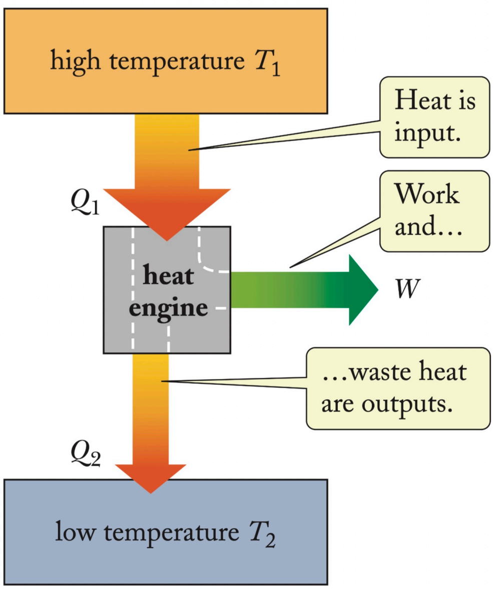

Figure 5.2: Flowchart for a heat engine. The center cube represents the heat engine.

Figure 5.2 is a flowchart for the energy, showing the heat Q_H flowing into the engine from the high-temperature reservoir, the heat Q_C (waste heat) flowing out of the engine into the low-temperature reservoir, and the work generated. The work generated by the engine is the difference between Q_H and Q_C,

$$W = Q_1 - Q_2 \tag{5.5}$$

The efficiency of the engine is defined as *the ratio of this work to the heat absorbed from the high-temperature reservoi*:

$$e = \frac{W}{Q_{in}} = \frac{Q_H - |Q_C|}{Q_H} = 1 - \frac{|Q_C|}{Q_H} \tag{5.6}$$

5.3 Idea gas

Statements:
The ideal gas is a limiting case of a real gas when the density and the pressure of the latter tend to zero.The ideal gas may be thought of as consisting of atoms of infinitesimal size, exerting no forces on each other or on the walls of the container, except for instantaneous impact forces exerted during collisions.

Suppose we place these n moles of gas in a container of volume V at a temperature T. The gas will then exert a pressure p. Experiments show that—to a good approximation—*the pressure p, the volume V, and the temperature T of the n moles of gas are related by the **Ideal-Gas Law**:*

$$PV = nRT = NkT \tag{5.7}$$

Note Eq.(5.7) the physical quantity N of right hand side(RHS) is the **number of the particles**, k is Boltzman constant and T doesn't change. Here R is the universal gas constant, with the value

$$R = 8.31 J/mole \cdot K \tag{5.8}$$

From the Ideal-Gas Law, we can calculate one of the three quantities that character- ize the state of the gas (pressure, temperature, volume) if the other two are known.

5.4 Thermal properties

Temperature
A kelvin is equal in size to a Celsius degree, and the conversion between kelvins and degrees Celsius is approximately:

$$T_k(K) = T_c(\,^\circ C) + 273 \tag{5.9}$$

5.5 Heat Transfer

- **Conduction**
  If you stick one end of an iron rod into a fire and hold the other end in your

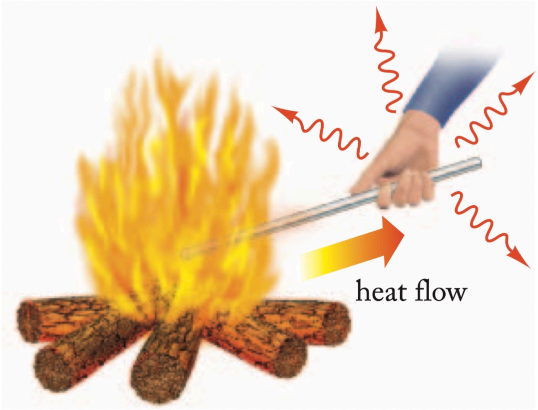

Figure 5.3: Heat flows from the hot end of the rod to the cold end.

hand (see Fig.5.3), you will feel the end in your hand gradually become warmer.This is an example of heat transfer by **conduction**. **Physical picture**:
The atoms and electrons in the hot end of the rod have greater kinetic and potential energies than those in other parts of the rod. In random collisions, these energetic atoms and electrons share some of their energy with their less energetic neighbors; these,in turn,share their energy with their neighbors,and so on.The result is a gradual diffusion of thermal energy from the hot end to the cold end.

Most metals are excellent conductors of heat, and also excellent conductors of electricity. The high thermal and electric conductivities of a metal are due to an abundance of "free" electrons within the volume of the metal; these are electrons that have become detached from their atoms—they move at high speeds, they wander all over the volume of the metal with little hindrance, and they are held back only at the surface of the metal. The free electrons behave like particles of a gas, and the metal acts like a bottle holding this gas.Typically, a free electron will move past a few hundred atoms before it suffers a collision. Because the electrons move such fairly large distances between collisions, they quickly transport energy from one end of a metallic rod to the other.The motion of the free electrons transports the thermal energy

- **Convection**
  In **convection**, the heat is stored in a moving fluid and is carried from one place to another by the motion of this fluid.

- **Radiation**
  In **radiation**, the heat is carried from one place to another by electromagnetic waves—for example, light waves, infrared waves, or radio waves.

5.6 Specific and Latent Heats

While the body is melting or boiling, it absorbs some amount of heat **without any increase of temperature**.This heat represents the energy required to loosen and break the bonds that hold the atoms inside the solid or liquid.
The heat absorbed during the change of state(or phase change) is called the **latent heat** or the heat of transformation, and more specifically, the **heat of fusion** or the **heat of vaporization**, for the change of state from solid to liquid or from liquid to gas, respectively.

$$q = mL \tag{5.10}$$

L is the **latent heats** with the unit J/kg.

While the body is heated up, it aborbs some amount of heat energy **without any change of states**. This heat is used to increase the kinetic energy of microscopic motion of atoms or molecules inside the solid(liquid or gas).
The heat necessary to raise the temperature of 1 kg of a material by $1\,°C$ is called the **specific heat capacity**, or the **specific heat**, usually designated by the symbol c.

$$Q = cm\Delta T \tag{5.11}$$

c is the **specific heats** with the unit $J/(kg \cdot K)$.

5.7 Thermal Expansion

If the pressure is held constant ($\Delta P = 0$), the volume of a given amount of gas will increase with the temperature [see Eq.(5.7)]. Such an increase of volume with temperature also occurs for solids and liquids; this phenomenon is called **thermal expansion**. However, the thermal expansion of solids and of liquids is much less than that of gases. Here we introduce the **expansion coefficient**,

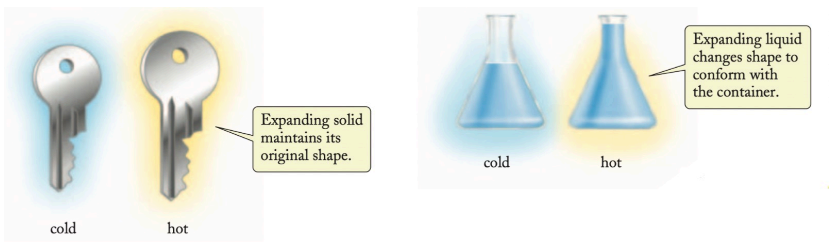

Figure 5.4: (LHS)Thermal expansion of a solid. (RHS) Thermal expansion of a liquid. The expansion of the flask has been neglected.

$$\begin{cases} \dfrac{\Delta L}{L_o} = \alpha_L \Delta T, \\ \dfrac{\Delta A}{A_o} = \alpha_A \Delta T, \\ \dfrac{\Delta V}{V_o} = \alpha_V \Delta T. \end{cases} \tag{5.12}$$

where L_o, A_o and V_o is the original length, area and volume of the heated object. In the meanwhile, α_L is the ***coefficient of linear expansion****, α_A is the* ***coefficient of area expansion*** *and α_V is the* ***coefficient of volum expansion****.*

Just read the Eq.(5.12) and understanding it with picture in your mind. For the case of linear expansion, it means the increment percentage of ratio ΔL to the length L_o ($\Delta L/L_o$) is directly proportional to the increment of temperature ΔT.

Chapter 6

Mordern Physics*

6.1 Quantum Phenomena

Photons
Photoelectric effect

6.2 Atomic

Rutherford
Bohr models
Atomic energy levels
Atomic spectra

6.3 Nuclear and Particle Physics

Radioactivity
Nuclear reactions
Fundalmental particles

6.4 Relativity

Time dilation
Length comtraction
Mass-energy equivalence

Chapter 7

Miscellaneous*

7.1 General Topics

History of Physics
Genral questions that overlap several major topics

7.2 Analytical Skills

Graphical analysis
Measurement
Math skills

7.3 Contemporary Physics

Astrophysics
Superconductivity
Chaos theory

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- https://en.wikipedia.org/wiki/Physics
  (Miscellaneous and modern physics are available here.)
- https://www.youtube.com/channel/UCV5U9yEfm0adktNL710UP0w/videos
  (Intuitional physical experiments will be useful for your picture construction.)
- https://www.youtube.com/channel/UCmUqTcxmzgnQ0TsBSzG6orw/videos
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