MINISTRY OF EDUCATION AND SCIENCE,
YOUTH AND SPORT OF UKRAINE

National Aerospace University "Kharkiv Aviation Institute"

Andriy Okhrimovskyy, Oksana Podshyvalova

MECHANICS AND THERMODYNAMICS

Guidance Manual for Recitation

Kharkiv "KhAI" 2012

УДК 531 + 536

О–92

Подано варіанти задач для семи практичних занять з фізики, що охоплюють теми: “Механіка”, “Механічні коливання та хвилі”, “Молекулярна фізика”, “Основи термодинаміки”. До кожної теми наведено таблицю з формулами.

Для англомовних студентів університету.

Reviewers: cand. of phys. & math. science, assc. prof. Gavrylova T.V.,
cand. of phys. & math. science, assc. prof. Kazachkov O.R.

ISBN 978-966-662-252-8

Okhrimovskyy, A.M.

O–92 Mechanics and Thermodynamics: guidance manual for recitation / A. M. Okhrimovskyy, O. V. Podshyvalova. — Kharkiv: National Aerospace University “KhAI”, 2012. — 72 p.

Manual contains set of problems to seven recitation classes offered by the Physics department of the National Aerospace University “Kharkiv Aviation Institute”. Guidance embraces the following topics: “Mechanics”, “Mechanical Oscillations and Waves”, “Molecular Physics”, “Thermodynamics”. Each chapter is supplied by a table with basic equations.

For english-speaking students of National Aerospace University “Kharkiv Aviation Institute”.

Figs. 12. Tables 7. Bibl.: 7 items

ISBN 978-966-662-252-8 **UDK 531+536**

Contents

Introduction 4

Chapter 1. Kinematics of Translational Motion 5

Chapter 2. Dynamics of Translational Motion 12

Chapter 3. Kinematics and Dynamics of Rotational Motion 21

Chapter 4. Work and Energy Conservation Law 32

Chapter 5. Mechanical Oscillations and Waves 40

Chapter 6. Molecular Physics and Ideal Gas Law 49

Chapter 7. Thermodynamics 55

Answers 63

Appendix 68

Bibliography 71

INTRODUCTION

Problem solving is an important part of studying physics. It impels students to work constructively and independently, teaches them to analyze phenomena, define principal factors, and neglect unimportant details thus brining them to scientific research. The goal of this manual is to help students master basic methods of problem solving in physics.

Problems given in this manual cover a wide range of questions within the course "Experimental and Theoretical Physics", namely those dealing with: "Kinematics of Translational Motion", "Dynamics of Translational Motion", "Kinematics and Dynamics of Rotational Motion", "Work and Energy Conservation Law", "Mechanical Oscillations and Waves", "Molecular Physics and Ideal Gas Law", "Thermodynamics". Most of problems were taken from [1–3]. The structure of the manual is similar to the structure of analogous publication in Ukrainian [7].

All chapters are intended for practical application of theoretical knowledge acquired at lectures. At the beginning of every chapter, there is a table containing the main definitions and physical laws which relate to the topic of the chapter. Also, we provide students with references to corresponding chapters in textbooks where they can find examples of how to solve typical problems. We hope it will stimulate them to read textbooks as well. Every chapter consists of five cases with five problems in each. At the end of the manual, we give answers to all problems.

Some physical quantities required for problem solving are introduced in Appendix which also includes some equations from calculus and vector algebra.

We welcome suggestions and comments from our readers and wish our students great success in studying physics.

Chapter 1

KINEMATICS OF TRANSLATIONAL MOTION

Equation number	Equation	Equation title	Comments
1	2	3	4
1.1	$\vec{\boldsymbol{r}} = x\vec{\boldsymbol{i}} + y\vec{\boldsymbol{j}} + z\vec{\boldsymbol{k}}$	Position vector	$\vec{\boldsymbol{i}}$, $\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{k}}$ are unit vectors; x, y, z are Cartesian coordinates
1.2	$r = \sqrt{x^2 + y^2 + z^2}$	Length of position vector	
1.3	$\vec{\boldsymbol{v}} = \frac{d\,\vec{\boldsymbol{r}}}{d\,t}$; $\vec{\boldsymbol{v}} = v_x\vec{\boldsymbol{i}} + v_y\vec{\boldsymbol{j}} + v_z\vec{\boldsymbol{k}}$	Instantaneous velocity vector	$v_x = \frac{dx}{dt}$, $v_y = \frac{dy}{dt}$, $v_z = \frac{dz}{d\,t}$
1.4	$v = \sqrt{v_x^2 + v_y^2 + v_z^2}$	Speed (magnitude of velocity vector)	
1.5	$v = \frac{ds}{dt}$, $s = \int\limits_0^t v(t)\,dt$	Relation of pathway s to the speed v	

1	2	3	4
1.6	$\vec{\boldsymbol{a}} = \dfrac{d\,\vec{\boldsymbol{v}}}{d\,t} = \dfrac{d^2\vec{\boldsymbol{r}}}{d\,t^2}$; $\vec{\boldsymbol{a}} = a_x\vec{\boldsymbol{i}} + a_y\vec{\boldsymbol{j}} + a_z\vec{\boldsymbol{k}}$	Instantaneous acceleration vector	$a_x = \dfrac{d\,v_x}{d\,t}$, $a_y = \dfrac{d\,v_y}{d\,t}$, $a_z = \dfrac{d\,v_z}{d\,t}$
1.7	$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$	Magnitude of acceleration	
1.8	$\vec{\boldsymbol{a}}_\tau = \dfrac{dv}{dt}\vec{\boldsymbol{\tau}}$, $\vec{\boldsymbol{a}}_n = \dfrac{v^2}{R}\vec{\boldsymbol{n}}$, $\vec{\boldsymbol{a}} = \vec{\boldsymbol{a}}_\tau + \vec{\boldsymbol{a}}_n$, $a = \sqrt{a_n^2 + a_\tau^2}$	Tangential and centripetal components of acceleration	$\vec{\boldsymbol{\tau}}$ is a unit vector tangent to trajectory; $\vec{\boldsymbol{n}}$ is a unit vector normal to the trajectory; R is a radius of curvature
1.9	$\vec{\boldsymbol{v}} = \vec{\boldsymbol{v}}(0) + \int\limits_0^t \vec{\boldsymbol{a}}(t)\,dt$	Velocity vector	
1.10	$\vec{\boldsymbol{r}} = \vec{\boldsymbol{r}}(0) + \int\limits_0^t \vec{\boldsymbol{v}}(t)\,dt$	Position vector	

Pre-Class Reading: [1] *chap.* 2 & 3; [2] *chap.* 2 & 3; [3] *chap.* 2 & 4.

Case 1.1

1.1.1. The vector position of a particle varies in time according to the expression $\vec{\boldsymbol{r}} = (3.00\vec{\boldsymbol{i}} - 6.00t^2\vec{\boldsymbol{j}})$ m. (a) Find expressions for the velocity and acceleration as functions of time. (b) Determine the particle's position and velocity at $t = 1.00$ s.

1.1.2. A web page designer creates an animation in which a dot on a computer screen has a position of $\vec{\boldsymbol{r}} = [4.0cm + (2.5\text{ cm/s}^2)t^2]\vec{\boldsymbol{i}} + (5.0\text{ cm/s})t\vec{\boldsymbol{j}}$. (a) Find the magnitude and direction of the dot's average velocity between $t = 0$ and $t = 2.0$ s. (b) Find the magnitude and direction of the instantaneous velocity at $t = 0$, $t = 1.0$ s, and $t = 2.0$ s. (c) Sketch the dot's trajectory from $t = 0$ to $t = 2.0$ s.

1.1.3. A faulty model rocket moves in the xy-plane (the positive y-direction is vertically upward). The rocket's acceleration has components $a_x(t) = \alpha t^2$ and $a_y(t) = \beta - \gamma t$, where $\alpha = 2.50$ m/s^4, $\beta = 9.00$ m/s^2, and $\gamma = 1.40$ m/s^3. At $t = 0$ the rocket is at the origin and has velocity $\vec{\boldsymbol{v}}_0 = v_{0x}\vec{\boldsymbol{i}} + v_{0y}\vec{\boldsymbol{j}}$ with $v_{0x} = 1.00$ m/s and $v_{0y} = 7.00$ m/s. (a) Calculate the velocity and position vectors as functions of time. (b) What is the maximum height reached by the rocket? (c) What is the horizontal displacement of the rocket when it returns to $y = 0$?

1.1.4. An automobile whose speed is increasing at a rate of 0.600 m/s^2 travels along a circular road of radius 20.0 m. When the instantaneous speed of the automobile is 4.00 m/s, find (a) the tangential acceleration component, (b) the centripetal acceleration component, and (c) the magnitude and direction of the total acceleration.

1.1.5. A particle is located by the position described by the vector $\vec{\boldsymbol{r}} = (c_1 - c_2 t)\vec{\boldsymbol{i}} + (d_1 + d_2 t + d_3 t^2)\vec{\boldsymbol{j}}$ where $c_1 = 12$ m, $c_2 = 2.0$ m/s, $d_1 = -7.2$ m, $d_2 = -6.0$ m/s, and $d_3 = 0.80$ m/s^2. a) At what time(s) does the particle pass through the position $x = 0$ m? b) At what time(s), and where, does the particle cross the line $x = y$? c) Sketch the particle's trajectory from $t = -10$ s to $t = +10$ s.

Case 1.2

1.2.1. An apple drops from the tree and falls freely. The apple is originally at rest a height H above the top of the grass of a thick lawn, which is made of blades of grass of height h. When the apple enters the grass, it slows down at a constant rate so that its speed is 0 when it reaches ground level. (a) Find the speed of the apple just before it enters the grass. (b) Find the acceleration of the apple while it is in the grass. (c) Sketch the $y-t$, v_y-t, and a_y-t graphs for the apple's motion.

1.2.2. If $\vec{r} = bt^2\vec{i} + ct^3\vec{j}$, where b and c are positive constants, when does the velocity vector make an angle of 45.0° with the x-and y-axes?

1.2.3. A rocket is fired at an angle from the top of a tower of height $h_0 = 50.0$ m. Because of the design of the engines, its position coordinates are of the form $x(t) = A + Bt^2$ and $y(t) = C + Dt^3$, where A, B, C, and D are constants. Furthermore, the acceleration of the rocket 1.00 s after firing is if $\vec{a} = (4.00\vec{i} + 3.00\vec{j})$ m/s^2. Take the origin of coordinates to be at the base of the tower. (a) Find the constants A, B, C, and D, including their **SI** units. (b) At the instant after the rocket is fired, what are its acceleration vector and its velocity? (c) What are the x- and y-components of the rocket's velocity 10.0 s after it is fired, and how fast is it moving? (d) What is the position vector of the rocket 10.0 s after it is fired?

1.2.4. A ball swings in a vertical circle at the end of a rope 2.00 m long. When the ball is 36.87° past the lowest point on its way up, its total acceleration is $(-6.50\vec{i} + 10.75\vec{j})$ m/s^2. At that instant, (a) sketch a vector diagram showing the components of its acceleration, (b) determine the magnitude of its radial acceleration, and (c) determine the speed and velocity of the ball.

1.2.5. The position of a particle in a given coordinate system is $\vec{r}(t) = (-6 + 4t^2)\vec{i} + (-4 + 3t)\vec{j}$, where the distances are in meters when t is in seconds. a) At what time will the particle cross the y -axis? b) At what time will it cross the x-axis? c) Can you find an equation that relates the y-coordinate to the x-coordinate and therefore gives the trajectory in the xy-plane?

Case 1.3

1.3.1. Two cars, A and B, travel in a straight line. The distance of A from the starting point is given as a function of time by $X_A(t) = \alpha t + \beta t^2$, with $\alpha = 2.60$ m/s and $\beta = 1.20$ m/s^2. The distance of B from the starting point is $X_B(t) = \gamma t^2 - \delta t^3$, with $\gamma = 2.80$ m/s^2 an $\delta = 0.20$ m/s^3. (a) Which car is ahead just after they leave the starting point? (b) At what time(s) are the cars at the same point? (c) At what time(s) is the distance from A to B neither increasing nor decreasing? (d) At what time(s) do A and B have the same acceleration?

1.3.2. A jet plane is flying at a constant altitude. At time $t_1 = 0$ it has components of velocity $v_x = 90$ m/s, $v_y = 110$ m/s. At time $t_2 = 30.0$ s the components are $v_x = -170$ m/s, $v_y = 40$ m/s. (a) Sketch the velocity vectors at t_1 and t_2. How do these two vectors differ? For this time interval calculate (b) the components of the average acceleration, and (c) the magnitude and direction of the average acceleration.

1.3.3. A bird flies in the xy-plane with a velocity vector given by $\vec{\boldsymbol{v}} = (\alpha - \beta t^2)\vec{\boldsymbol{\imath}} + \gamma t \vec{\boldsymbol{\jmath}}$, with $\alpha = 2.4$ m/s, $\beta = 1.6$ m/s^3, and $\gamma = 4.0$ m/s^2. The positive y-direction is vertically upward. At $t = 0$ the bird is at the origin. (a) Calculate the position and acceleration vectors of the bird as functions of time. (b) What is the bird's altitude (y-coordinate) as it flies over $x = 0$ for the first time after $t = 0$?

1.3.4. A particle is observed to move with the coordinates $x(t) = (1.5 \text{ m/s})t + (-0.5 \text{ m/s}^2)t^2$ and $y(t) = 6 \text{ m} + (-3 \text{ m/s})t + (1.5 \text{ m/s}^2)t^2$. (a) What are the particle's position, velocity and acceleration? (b) At what time(s) are the velocity's horizontal and vertical components equal?

1.3.5. At a given moment, a fly moving through the air has a velocity vector that changes with time according to $v_x = 2.2$ m/s, $v_y = (3.7 \text{ m/s})t$, and $v_z = (-1.2 \text{ m/s}^3)t^2 + 3.3$ m/s, where t is measured in seconds. What is the fly's acceleration?

Case 1.4

1.4.1. At $t = 0$, a particle moving in the xy plane with constant acceleration has a velocity of $\vec{\boldsymbol{v}}_i = (3.00\vec{\boldsymbol{\imath}} - 2.00\vec{\boldsymbol{\jmath}})$ m/s and is at the origin. At $t = 3.00$ s, the particle's velocity is $\vec{\boldsymbol{v}} = (9.00\vec{\boldsymbol{\imath}} + 7.00\vec{\boldsymbol{\jmath}})$ m/s. Find (a) the acceleration of the particle and (b) its coordinates at any time t.

1.4.2. A particle initially located at the origin has an acceleration of $\vec{\boldsymbol{a}} = 3.00\vec{\boldsymbol{\jmath}}$ m/s^2 and an initial velocity of $\vec{\boldsymbol{v}}_i = 5.00\vec{\boldsymbol{\imath}}$ m/s. Find (a) the vector position and velocity at any time t and (b) the coordinates and speed of the particle at $t = 2.00$ s.

1.4.3. The coordinates of a bird flying in the xy-plane are given by $x(t) = \alpha t$ and $y(t) = 3.0m - \beta t^2$, where $\alpha = 2.4$ m/s and $\beta = 1.2$ m/s^2. (a) Sketch the path of the bird between $t = 0$ and $t = 2.0$ s. (b) Calculate the velocity and acceleration vectors of the bird as functions of time. (c) Calculate the magnitude and direction of the bird's velocity and acceleration at $t = 2.0$ s. (d) Sketch the velocity and acceleration vectors at $t = 2.0$ s. At this instant, is the bird speeding up, is it slowing down, or is its speed instantaneously not changing? Is the bird turning? If so, in what direction?

1.4.4. A particle moves in such a way that its coordinates are $x(t) = A\cos\omega t$, $y(t) = A\sin\omega t$. Calculate the x- and y-components of the velocity and the acceleration of the particle.

1.4.5. The Moon circles Earth at a distance of $3.84 \cdot 10^5$ km. The period is approximately 28 d. What is the magnitude of the moon's acceleration, in units of g as the Moon orbits Earth?

Case 1.5

1.5.1. A bag is dropped from a hot-air bag balloon. Its height is given by the formula $h = H - ut - (u/B)e^{-Bt}$. (a) What are the dimensions of B ? (b) What is the initial velocity? (c) What is the velocity as $t \to \infty$ (d) Calculate the acceleration at $t = 0$ and $t \to \infty$.

1.5.2. A boy shoots a rock with an initial velocity of 24 m/s straight up from his slingshot. He quickly reloads and shoots other rock in the same way 2.0 s later. (a) At what time and (b) at what height do the rocks meet? (c) What is the velocity of each rock when they meet?

1.5.3. The motion of a planet about a star is described by the vector $\vec{\boldsymbol{r}} = R\cos(\omega t)\vec{\boldsymbol{i}} + R\sin(\omega t)\vec{\boldsymbol{j}}$. Calculate a) the acceleration vector of the planet and b) normal and tangential components of acceleration.

1.5.4. An automobile moves on a circular track of radius 0.5 km. It starts from rest from point $(x, y) = (0.5 \text{ km}, 0 \text{ km})$ and moves counterclockwise with a steady tangential acceleration such that it returns to starting point with speed 32.0 m/s after one lap. (The origin of the system is at the center of the circular track.) What is the car's velocity when it is one-eighth of the way track?

1.5.5. An airplane flies due south with respect to the ground at an air speed of 900 km/h for 2.0 h before turning and moving southwest with respect to ground for 3.0 h. During the entire trip, a wind blows in the easterly direction at 120 km/h. (a) What is the plane's average speed with respect to the ground? (b) What is the plane's final position.(c) What is the plane's average velocity with respect to the ground?

Chapter 2

DYNAMICS OF TRANSLATIONAL MOTION

Equation number	Equation	Equation title	Comments
1	2	3	4
2.1	$\vec{\boldsymbol{p}} = m\vec{\boldsymbol{v}}$	Momentum of a point particle	$\vec{\boldsymbol{v}}$ is a velocity; m is a mass
2.2	$\frac{d\vec{\boldsymbol{p}}}{dt} = \vec{\boldsymbol{F}}_{\Sigma}$	Newton's second law (universal format)	$\vec{\boldsymbol{F}}_{\Sigma}$ is a net (resultant) force applied
2.3	$m\frac{d^2\vec{\boldsymbol{r}}}{dt^2} = m\frac{d\vec{\boldsymbol{v}}}{dt} =$ $= m\vec{\boldsymbol{a}} = \vec{\boldsymbol{F}}_{\Sigma}$	Newton's second law (differential form)	$\vec{\boldsymbol{r}}$ is a position vector of the particle
2.4	$M\frac{d\vec{\boldsymbol{V}}_C}{dt} = \vec{\boldsymbol{F}}_{\Sigma}^{ext}$	Law of motion for center of mass of a system of particles	M is a total mass of the system, $\vec{\boldsymbol{F}}_{\Sigma}^{ext}$ is a net external force applied
2.5	$\vec{\boldsymbol{R}}_C = \frac{\sum_{i=1}^{N} \vec{\boldsymbol{r}}_i m_i}{\sum_{i=1}^{N} m_i}$	Center of mass position vector	$\vec{\boldsymbol{r}}_i$ is a position vector of an individual particle

1	2	3	4
2.6	$\vec{\boldsymbol{V}}_C = \dfrac{\sum\limits_{i=1}^{N} m_i \vec{\boldsymbol{v}}_i}{\sum\limits_{i=1}^{N} m_i} = \dfrac{\vec{\boldsymbol{p}}_\Sigma}{M}$	Velocity of the center of mass of N particles	$\vec{\boldsymbol{p}}_\Sigma$ is a total momentum of the system
2.7	$\vec{\boldsymbol{p}}_\Sigma = \sum\limits_{i=1}^{N} \vec{\boldsymbol{p}}_i = \text{const}$	Momentum conservation law	For an isolated system, $(\vec{\boldsymbol{F}}_\Sigma^{ext} = 0)$
2.8	$\vec{\boldsymbol{F}} = m\vec{\boldsymbol{g}}$	Gravity force	$\vec{\boldsymbol{g}}$ is an acceleration due to gravity
2.9	$\vec{\boldsymbol{F}}_A = -\vec{\boldsymbol{g}}\rho V$	Buoyancy force	ρ is a mass density of a fluid (gas); V is a displaced fluid volume
2.10	$\vec{\boldsymbol{F}} = -k\vec{\boldsymbol{x}}$	Elastic force (Hook's law)	k is a spring constant; x is a displacement
2.11	$\vec{\boldsymbol{F}}_{12} = -G\dfrac{m_1 m_2}{r_{12}^2}\dfrac{\vec{\boldsymbol{r}}_{12}}{r_{12}}$	Universal gravitation force law	G is a gravitational constant; m_1, m_2 are masses of particles; $\vec{\boldsymbol{r}}_{12}$ is a position vector of the second body with respect to the first one
2.12	$F = PA$	Pressure force	P is a pressure; A is a surface area
2.13	$F = T$	Tension force	Acts along the thread

1	2	3	4
2.14	$F = N$	Normal contact force	Perpendicular to a contact surface
2.15	$F = \mu N$	Kinetic friction force	Opposite to motion; μ is a kinetic friction coefficient
2.16	$\vec{\boldsymbol{F}} = -r\vec{\boldsymbol{v}}$	Linear drag force (low speed)	r is a linear resistance coefficient, $\vec{\boldsymbol{v}}$ is a velocity of the body
2.17	$\vec{\boldsymbol{F}} = -\frac{1}{2}C_D\rho Av\vec{\boldsymbol{v}}$	Quadratic drag force exerted on an object moving with a high speed v in a medium	ρ is the mass density of a medium A is a cross-sectional area of an object, C_D is a dimensionless drag coefficient
2.18	$\vec{\boldsymbol{F}}_{\text{thr}} = -\vec{\boldsymbol{u}}\frac{dm}{dt}$	Thrust force	$\vec{\boldsymbol{u}}$ is a relative velocity of an escaping or incoming mass
2.19	$\vec{\boldsymbol{F}} = q\vec{\boldsymbol{E}}$	Electrostatic force	q is a charge; $\vec{\boldsymbol{E}}$ is an electric field vector
2.20	$\vec{\boldsymbol{F}} = q\vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}}$	Magnetic force	$\vec{\boldsymbol{B}}$ is a magnetic field vector

Pre-Class Reading: [1] *chap.* 4 & 5; [2] *chap.* 4 & 5; [3] *chap.* 5 & 6.

Case 2.1

2.1.1. Two objects are moving in the xy-plane. The first one of mass 2.4 kg, has a velocity $\vec{\boldsymbol{v}}_1 = -(2.0\vec{\boldsymbol{i}} + 3.5\vec{\boldsymbol{j}})$ m/s; the second one, of mass 1.6 kg, has a velocity $\vec{\boldsymbol{v}}_2 = (1.8\vec{\boldsymbol{i}} - 1.5\vec{\boldsymbol{j}})$ m/s. (a) What is the total momentum of the system? (b) If the system observed later shows that the 2.4-kg object has $\vec{\boldsymbol{v}}'_1 = (2.5\vec{\boldsymbol{i}})$ m/s, what is the velocity of the 1.6-kg object? Assume that objects interact only on each other.

2.1.2. Two blocks, each with weight W, are held in place on a fric-

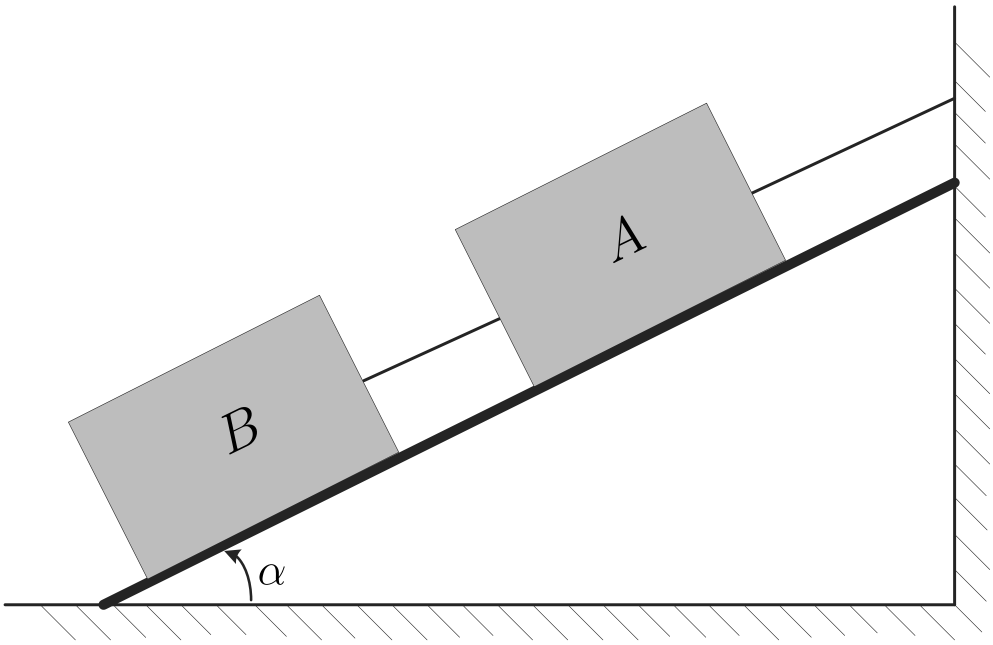

Figure 2.1. Problem 2.1.2

tionless incline (Fig. 2.1). In terms of W and the angle α of the incline, calculate the tension in (a) the rope connecting the blocks and (b) the rope that connects block A to the wall. (c) Calculate the magnitude of the force that the incline exerts on each block. (d) Interpret your answers for the cases $\alpha = 0$ and $\alpha = 90°$.

2.1.3. Two children of masses 25 and 30 kg, respectively, stand 2.0 m apart on skates on a smooth ice rink. The lighter of the children holds a 3.0-kg ball and throws it to the heavier child. After the throw the lighter child recoils at 2.0 m/s. With what speed will the center of mass of two children and the ball move?

2.1.4. A 50.0-kg stunt pilot who has been diving her airplane vertically polls out of the dive by changing her course to a circle in a vertical plane. (a) If at the lowest point of the circle, the plane's speed is 95.0 m/s, what is the minimum radius of the circle for the acceleration at this point not to exceed 4.00 g? (b) What is the apparent weight of the pilot at the lowest point of the pullout?

2.1.5. Calculate the force required to pull an iron ball (of density 7.8 g/cm^3) of diameter 3.0 cm upward through a fluid at the constant speed 2.0 cm/s. Take the drag force proportional to the speed with the proportionality constant equal to 1.0 kg/s. Ignore the buoyant force.

Case 2.2

2.2.1. An electron ($m_e = 9.11 \cdot 10^{-31}$ kg) leaves one end of a TV picture tube with zero initial speed and travels in a straight line to the accelerating grid, which is 1.80 cm away. It reaches the grid with a speed of $3.00 \cdot 10^6$ m/s. If the accelerating force is constant, compute (a) the acceleration; (b) the time to reach the grid; (c) the net force. (You can ignore the gravitational force on the electron.)

2.2.2. A 9.00-kg block of ice, released from rest at the top of a 1.50-m-long frictionless ramp, slides downhill, reaching a speed of 2.50 m/s at the bottom. (a) What is the angle between the ramp and the horizontal? (b) What would be the speed of the ice at the bottom if the motion were opposed by a constant friction force of 12.0 N parallel to the surface of the ramp?

2.2.3. Consider the system shown in Fig. 2.2. Block A weighs 45.0 N, and block B weighs 25.0 N. Once block B is set into downward motion, it descends at a constant speed. (a) Calculate the coefficient of kinetic friction between the block A and the tabletop. (b) A cat of weight 30.0 N falls asleep on the top of the block B. If block B is now set into downward motion, what is its acceleration (magnitude and direction)?

2.2.4. Two small bodies are moving in the yz-plane. The first one, of mass 1.5 kg, has a velocity $\vec{\boldsymbol{v}}_1 = (2.00\vec{\boldsymbol{j}} - 3.60\vec{\boldsymbol{k}})$ m/s; the second one, of mass 2.5 kg, has a velocity $\vec{\boldsymbol{v}}_2 = (-1.80\vec{\boldsymbol{j}} + 2.40\vec{\boldsymbol{k}})$ m/s. Suppose that there has been a mass transfer so that both bodies have got the same mass. The total mass is conserved. What is the velocity of the first

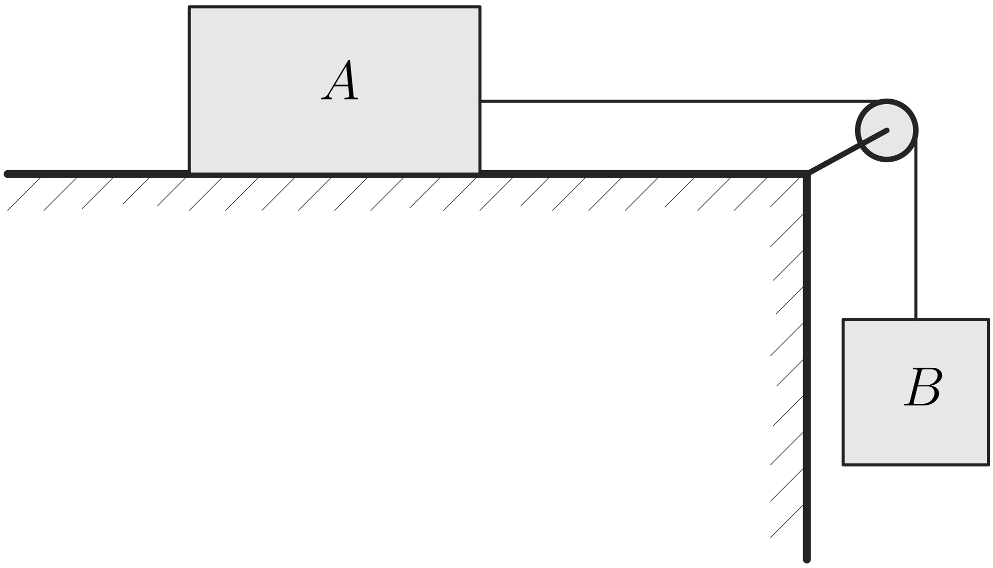

Figure 2.2. Problem 2.2.3

body $\vec{v}_1'$ if the velocity of the second one is $\vec{v}_2' = (-2.50\vec{i} + 1.25\vec{j})$ m/s?

2.2.5. A mallet forms a symmetric T-shape. The top of the T is a uniform iron block of mass 4.0 kg. The wooden handle is uniform, 1.2 m long, and has a mass of 2.0 kg. Where is the mallet's center of mass?

Case 2.3

2.3.1. A machine gun in automatic mode fires 20-g bullets with $v_{\text{bullet}} = 300$ m/s at 60 bullets/s. (a) If the bullets enter a thick wooden wall, what is the average force exerted against the wall? (b) If the bullets hit a steel wall and rebound elastically, what is the average force on the wall?

2.3.2. A light rope is attached to a block with mass 4.00 kg that rests on a frictionless, horizontal surface. The horizontal rope passes over a frictionless, massless pulley, and a block with mass m is suspended from the other end. When the blocks are released, the tension in the rope is 10.0 N. (a) Draw two free-body diagrams, one for the 4.00-kg block and one for the block with mass m. (b) What is the acceleration of either block? (c) Find the mass m of the hanging block. (d) How does the tension compare to the weight of the hanging block?

2.3.3. A 25.0-kg box of textbooks rests on a loading ramp that makes an angle a with the horizontal. The coefficient of kinetic friction is 0.25, and the coefficient of static friction is 0.35. (a) As the angle α is increased, find the minimum angle at which the box starts to slip. (b) At this angle, find the acceleration once the box has begun to move. (c) At this angle, how fast will the box be moving after it has slid 5.0 m along the loading ramp?

2.3.4. Estimate (a) the mas of the Sun and (b) the orbital speed of the Earth. Assume that orbit is circular. Check the appendix for astronomical data.

2.3.5. A small sphere of mass 2.00 g is released from rest in a large vessel filled with oil. It experiences a resistive force proportional to its speed. The sphere reaches a terminal speed of 5.00 cm/s. Determine (a) the resistance coefficient of the oil and (b) the time at which the sphere reaches 63.2% of its terminal speed. Ignore the buoyant force.

Case 2.4

2.4.1. A billiard ball with velocity $\vec{\boldsymbol{v}} = (2.5\vec{\boldsymbol{\imath}})$ m/s strikes a stationary billiard ball of the same mass. After collision, the first billiard ball has a velocity $\vec{\boldsymbol{v}}_1 = (0.5\vec{\boldsymbol{\imath}} - 1.0\vec{\boldsymbol{\jmath}})$ m/s. What is the velocity of the second billiard ball?

2.4.2. The height achieved in a jump is determined by the initial vertical velocity that the jumper is able to achieve. Assuming that this is a fixed number, how high can an athlete jump on Mars if she can clear 1.85 m on Earth? The radius of Mars is $3.4 \cdot 10^3$ km. The mass of Mars is $6.42 \cdot 10^{23}$ kg.

2.4.3. A physics student playing with an air hockey table (a frictionless surface) finds that if she gives the puck a velocity of 3.50 m/s along the length (1.75 m) of the table at one end, by the time it has reached the other end the puck has drifted 2.50 cm to the right but still has a velocity component along the length of 3.50 m/s. She correctly concludes that the table is not level and correctly calculates its inclination from the given information. What is the angle of inclination?

2.4.4. An airplane flies in a loop (a circular path in a vertical plane) of radius 160 m. The pilot's head always points toward the center of the loop. The speed of the airplane is not constant; the airplane goes slowest at the top of the loop and fastest at the bottom. (a) At the top of the loop, the pilot feels weightless. What is the speed of the airplane at this point? (b) At the bottom of the loop, the speed of the airplane is 288 km/h. What is the apparent weight of the pilot at this point? His true weight is 700 N.

2.4.5. A hammer is hanging by a light rope from the ceiling of a bus. The ceiling of the bus is parallel to the roadway. The bus is traveling in a straight line on a horizontal street. You observe that the hammer hangs at rest with respect to the bus when the angle between the rope and the ceiling of the bus is 74°. What is the acceleration of the bus?

Case 2.5

2.5.1. Three masses $m_1 = 0.3$ kg, $m_2 = 0.4$ kg, and $m_3 = 0.2$ kg

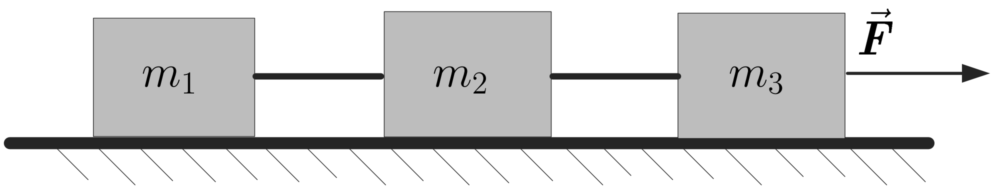

Figure 2.3. Problem 2.5.1

are connected by light cords to make a "train" sliding on a frictionless surface, as shown in a Fig. 2.3. They are accelerated by a constant horizontal force $F = 1.5$ N that pulls the m_3 mass to the right. What is the tension T in the cord (a) between the masses m_1 and m_2 and (b) between the masses m_2 and m_3.

2.5.2. Estimate the orbital radius of the Moon. Use 28 days as an approximate value of the orbital period of the Moon. Assume that the orbit is circular. Check the appendix for astronomical data.

2.5.3. An object of mass m is constrained to move in a circle of radius R by a central force F proportional to the speed v of the object, $F = Cv$. Calculate the proportionality coefficient C in terms of

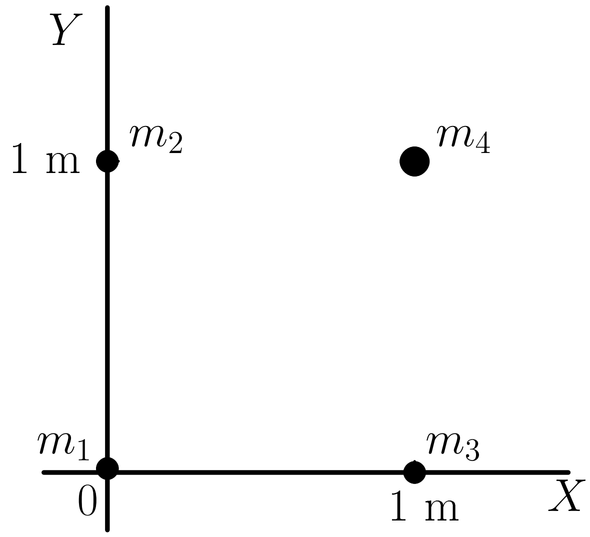

Figure 2.4. Problem 2.5.4

momentum of the object and radius R. (This kind of force acts on a charged object in a uniform magnetic field.)

2.5.4. A set of point masses is arrayed on the xy-plane. A mass of 1 kg is placed at the origin. Two similar masses are at the points $(x, y) = (1\text{ m}, 0)$ and $(0, 1\text{ m})$, respectively, and a fourth mass of 2 kg is at the point $(1\text{ m}, 1\text{ m})$. (See Fig. 2.4.) (a) Where is the center of mass? (b) Suppose the fourth mass 1 kg rather 2 kg. Without a detailed calculation, find the location of the center of mass in this case.

2.5.5. After ejecting a communication satellite, the space shuttle must make a correction to account for the change in a momentum. One of the thrusters with the exhaust speed of the gas relative to the rocket $u_{ex} = 10^3$ m/s is used to increase the orbital velocity by 10 m/s. What percent of the mass of the space shuttle must be discarded?

Chapter 3

KINEMATICS AND DYNAMICS OF ROTATIONAL MOTION

Equation number	Equation	Equation title	Comments
1	2	3	4
3.1	$\vec{\boldsymbol{\omega}} = \dfrac{d\vec{\boldsymbol{\theta}}}{dt}$	Angular velocity vector	$d\vec{\boldsymbol{\theta}}$ is an infinitesimal angle of rotation
3.2	$\vec{\boldsymbol{\alpha}} = \dfrac{d\vec{\boldsymbol{\omega}}}{dt}$	Angular acceleration vector	
3.3	$f = \dfrac{N}{t}$	Frequency of uniform rotation	N is a total number of revolutions per time t
3.4	$T = \dfrac{t}{N} = \dfrac{1}{f}$	Period of uniform rotation	
3.5	$l = \theta\, R$	Arc length (pathway of a particle)	θ is an angle of rotation in rad; R is a radius
3.6	$v = \omega\, R$	Speed of a particle	ω is an angular speed of rotation

1	2	3	4
3.7	$\vec{\boldsymbol{v}} = \vec{\boldsymbol{\omega}} \times \vec{\boldsymbol{r}}$	Velocity vector	$\vec{\boldsymbol{r}}$ is a position vector of the particle with respect to a point at the axis of rotation
3.8	$a_\tau = \dfrac{dv}{dt} = \alpha\, R$	Tangential acceleration component of the particle	α is an angular acceleration of the body
3.9	$\vec{\boldsymbol{a}}_\tau = \vec{\boldsymbol{\alpha}} \times \vec{\boldsymbol{r}}$	Vector of tangential acceleration	
3.10	$\vec{\boldsymbol{a}}_n = -\omega^2 \vec{\boldsymbol{r}}$	Centripetal acceleration vector	
3.11	$\vec{\boldsymbol{\omega}} = \text{const}$, $\vec{\boldsymbol{\alpha}} = 0$, $\theta = \theta_0 + \omega t$	Uniform rotation law	θ_0 is an initial angle of rotation
3.12	$\vec{\boldsymbol{\alpha}} = \text{const}$, $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$, $\omega = \omega_0 + \alpha t$	Law of uniformly accelerated rotation	ω_0 is an initial angular velocity
3.13	$\theta = \theta_0 + \int\limits_{t_0}^{t} \omega(t)\, dt$, $\omega = \omega_0 + \int\limits_{t_0}^{t} \alpha(t)\, dt$	General law of rotational motion ($\alpha \neq \text{const}$)	

1	2	3	4
3.14	$\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{r}} \times \vec{\boldsymbol{F}}$, $\tau = Fr\sin\varphi$	Torque and its magnitude with respect to origin	$\vec{\boldsymbol{F}}$ is a force vector; $\vec{\boldsymbol{r}}$ is a position vector of the point at which force acts; φ is an angle between $\vec{\boldsymbol{F}}$ and $\vec{\boldsymbol{r}}$
3.15	$J = mr^2$	Moment of inertia of a point particle	m is a mass of the particle; r is a distance from axis of rotation to the particle
3.16	$J = \sum\limits_{i=1}^{N} m_i r_i^2$	Moment of inertia of a system of particles	m_i is a mass of the i-th particle on a distance r_i from the axis of rotation
3.17	$J_z = \int\limits_m r^2\,dm = \int\limits_V \rho r^2\,dV$	Moment of inertia of a rigid body about z-axis	ρ is a mass density of the body material; dV is an infinitesimal volume
3.18	a) $J_z = \frac{1}{12}ml^2$; b) $J_z = \frac{1}{3}ml^2$	Moment of inertia of a uniform rod about perpendicular axis passing through its: a) center of mass; b) edge	m is a mass of the rod; l is a length of the rod

1	2	3	4
3.19	$J_z = mR^2$	Moment of inertia of a thin ring about an axis perpendicular to a ring's plane and passing through its center	m is a mass of the ring; R is a radius of the ring
3.20	$J_z = \frac{1}{2}mR^2$	Moment of inertia of a uniform cylinder (disk) about its axis of symmetry	m is a mass of the cylinder; R is a radius of the cylinder
3.21	$J_z = \frac{2}{5}mR^2$	Moment of inertia of a uniform ball about its axis of symmetry	m is a mass of the ball; R is a radius of the ball
3.22	$\vec{\boldsymbol{L}} = \vec{\boldsymbol{r}} \times \vec{\boldsymbol{p}}$	Vector of angular momentum of the point particle	$\vec{\boldsymbol{p}}$ is a momentum of the particle; $\vec{\boldsymbol{r}}$ is a position vector of the particle
3.23	$L_\omega = J_\omega \omega$	Angular momentum of a rigid body about axis of rotation	J_ω is a moment of inertia about the axis of rotation; ω is an angular speed

1	2	3	4
3.24	$J_{\text{O}} = J_{\text{C}} + ma^2$	Parallel axis theorem	J_{C} is a moment of inertia of the body about a parallel axis passing through the center of mass; m is a mass of the body; a is a distance between axises
3.25	$\dfrac{d\vec{\boldsymbol{L}}}{dt} = \vec{\boldsymbol{\tau}}_{\Sigma}$	Torque-angular-momentum equation	$\vec{\boldsymbol{\tau}}_{\Sigma}$ is a total external torque
3.26	$J_\omega \alpha = \tau_\omega$	The rotational analog of Newton's second law	J_ω is a moment of inertia about the axis of rotation; α is an angular acceleration; τ_ω is a torque about the axis of rotation
3.27	$\sum\limits_{i=1}^{N} \vec{\boldsymbol{L}}_i = \text{const}$	Angular momentum conservation law	For isolated system ($\vec{\boldsymbol{\tau}}_{\Sigma} = 0$), $\vec{\boldsymbol{L}}_i$ is an angular momentum of individual objects of the system

Pre-Class Reading: [1] *chap.* 9 & 10; [2] *chap.* 9 & 10; [3] *chap.* 10 & 11.

Case 3.1

3.1.1. A fan blade rotates with the angular velocity given by $\omega_z(t) = \gamma - \beta t^2$ where $\gamma = 5.00$ rad/s and $\beta = 0.800$ rad/s^3. (a) Calculate the angular acceleration as a function of time. (b) Calculate the instantaneous angular acceleration α_z at $t = 3.00$ s and the average angular acceleration α_{av-z} for the time interval $t = 0$ to $t = 3.00$ s. How do these two quantities compare? If they are different, why so?

3.1.2. Four small spheres, each of which you can regard as a point

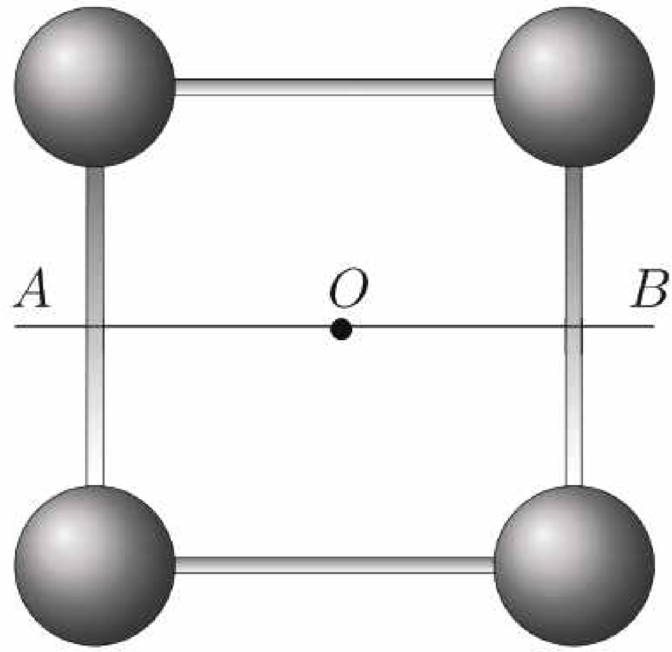

Figure 3.1. Problem 3.1.2

of mass 0.100 kg, are arranged in a square 0.200 m on a side and connected by extremely light rods (Fig. 3.1). Find the moment of inertia of the system about an axis (a) through the center of the square, perpendicular to its plane (an axis through point O in the figure); (b) bisecting two opposite sides of the square (an axis along the line AB in the figure); (c) that passes through the centers of the upper left and lower right spheres and through point O.

3.1.3. A woman with mass 55 kg is standing on the rim of a large disk that is rotating at 0.50 rev/s about an axis through its center. The disk has mass 90 kg and radius 2.0 m. Calculate the magnitude of the total angular momentum of the woman-plus-disk system. (Assume that you can treat the woman as a point.)

3.1.4. One force acting on a machine part is $\vec{\boldsymbol{F}} = (5.00\ \text{N})\vec{\boldsymbol{i}} + (4.00\ \text{N})\vec{\boldsymbol{j}}$. The vector from the origin to the point where the force is applied is $\vec{\boldsymbol{r}} = (-0.40\ \text{m})\vec{\boldsymbol{i}} + (0.30\ \text{m})\vec{\boldsymbol{j}}$. (a) In a sketch, show $\vec{\boldsymbol{r}}$, $\vec{\boldsymbol{F}}$, and the origin. (b) Use the right-hand rule to determine the direction of the torque. (c) Calculate the vector torque produced by this force. Verify that the direction of the torque is the same as you obtained in part (b).

3.1.5. The flywheel of an engine has moment of inertia 2.50 kg·m^2 about its rotation axis. What constant torque is required to bring it up to an angular speed of 400 rev/min in 8.00 s, starting from rest?

Case 3.2

3.2.1. The angle θ through which a disk drive turns is given by $\theta(t) = a + bt + ct^3$, where a, b, and c are constants, t is in seconds, and θ is in radians. When $t = 0$, $\theta = \pi/4$ rad and the angular velocity is 2.00 rad/s, and when $t = 1.00$ s, the angular acceleration is 1.25 rad/s^2. (a) Find a, b, and c, including their units. (b) What is the angular acceleration when $\theta = \pi/4$ rad? (c) What are θ and the angular velocity when the angular acceleration is 3.60 rad/s^2?

3.2.2. Small blocks, each with mass m, are clamped at the ends and at the center of a rod of length L and negligible mass. Compute the moment of inertia of the system about an axis perpendicular to the rod and passing through (a) the center of the rod and (b) a point one-fourth of the length from one end.

3.2.3. Two little bullets of the masses $m_1 = 40$ g and $m_2 = 120$ g are connected by a weightless rod $l = 20$ cm long. The system rotates about the axis which is perpendicular to the rod and passes through the center of inertia of the system. Determine the angular momentum L of the system about axis of rotation. The rotation frequency $f = 3\ \text{s}^{-1}$.

3.2.4. What is the torque about the origin on a particle positioned at $\vec{\boldsymbol{r}} = (3.0\ \text{m})\vec{\boldsymbol{i}} - (1.0\ \text{m})\vec{\boldsymbol{j}} - (5.0\ \text{m})\vec{\boldsymbol{k}}$, exerted by a force of

$\vec{\boldsymbol{F}} = (2.0\ \text{N})\vec{\boldsymbol{i}} + (4.0\ \text{N})\vec{\boldsymbol{j}} + (3.0\ \text{N})\vec{\boldsymbol{k}}$?

3.2.5. A cord is wrapped around the rim of a solid uniform wheel

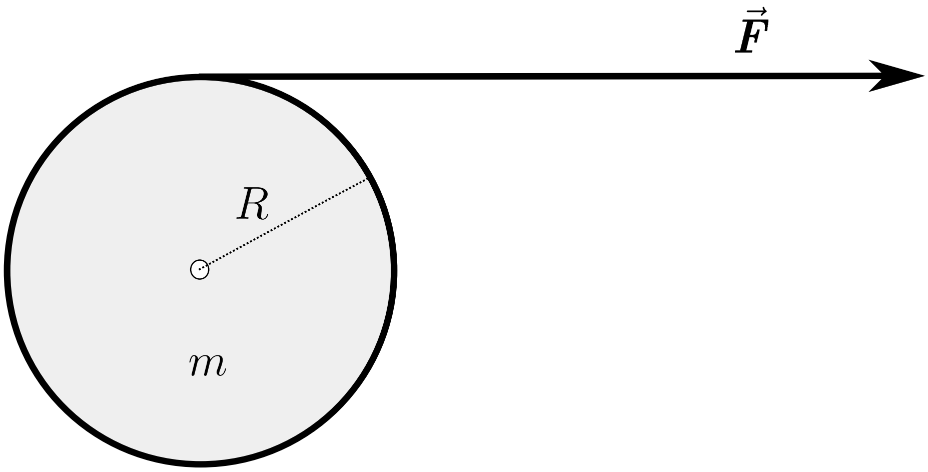

Figure 3.2. Problem 3.2.5

0.250 m in radius and of mass 10.0 kg as shown in a Fig. 3.2. A steady horizontal pull of 40.0 N to the right is exerted on the cord, pulling it off tangentially from the wheel. The wheel is mounted on frictionless bearings on a horizontal axle through its center. Compute the angular acceleration of the wheel and the acceleration of the part of the cord that has already been pulled off the wheel.

Case 3.3

3.3.1. At $t = 0$, a grinding wheel has an angular velocity of 24.0 rad/s. It has a constant angular acceleration of 30.0 rad/s^2 until a circuit breaker trips at $t = 2.00$ s. From then on, it turns through 420 rad as it coasts to a stop at constant angular acceleration. (a) Through what total angle did the wheel turn between $t = 0$ and the time it stopped? (b) At what time did it stop? (c) What was its acceleration as it slowed down?

3.3.2. Find the moment of inertia of a uniform ball with mass M and radius R about an axis at the surface of the ball.

3.3.3. (a) Calculate the magnitude of an angular momentum of the Earth in a circular orbit around the Sun. Is it reasonable to model it as a particle? (b) Calculate the magnitude of the Earth's angular momentum due to its rotation around an axis through the North and South Poles, modeling it as a uniform sphere. Consult Appendix for the astronomical data.

3.3.4. With what force F should you press down the brake block to

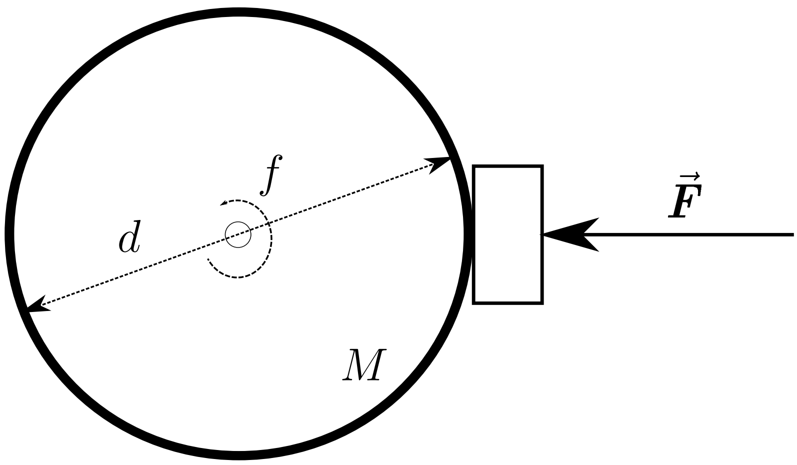

Figure 3.3. Problem 3.3.4

the wheel which does $f = 30$ rev/s for it to stop in $t = 20$ s? (Fig. 3.3) The wheel weights is 10 kg. The weight is distributed over the rim. The diameter d of the wheel is equal to 20 cm. The friction coefficient between the rim and the block is $\mu = 0.5$.

3.3.5. A wheel with moment of inertia $J = 240$ kg·m^2 is rotating at $f = 20$ rev/s. It comes to rest in $t = 1$ min if the engine that supports the rotation is turned off. Find the torque of friction force τ_f and number of turnovers N the wheel had done before it stopped?

Case 3.4

3.4.1. A turntable rotates with a constant angular acceleration of 2.25 rad/s^2. After 4.00 s it has rotated through an angle of 60.0 rad. What was the angular velocity of the wheel at the end of the 4.00-s interval?

3.4.2. A uniform pipe of 2.0 kg is a right cylinder which outer radius is 4.0 cm and inner radius is 3.0 cm. What is the moment of inertia of the pipe about its the axis of symmetry?

3.4.3. A diver comes off a board with arms straight up and legs straight down, giving her a moment of inertia about her rotation axis of

18 kg· m^2. She then tucks into a small ball, decreasing this moment of inertia to 3.6 kg· m^2. While tucked, she makes two complete revolutions in 1.0 s. If she hadn't tucked at all, how many revolutions would she have made in the 1.5 s from board to water?

3.4.4. A solid, uniform cylinder with mass 8.00 kg and diameter 20.0 cm is spinning at 240 rpm on a thin frictionless axle that passes along the cylinder axis. You design a simple friction brake to stop the cylinder by pressing the brake against the outer rim with a normal force. The coefficient of kinetic friction between the brake and rim is 0.333. What must the applied normal force be to bring the cylinder to rest after it has turned through 6.00 revolutions?

3.4.5. A braking wheel reduces the frequency of rotation uniformly from $f_1 = 360$ rpm to $f_2 = 180$ rpm at the time $t = 0.5$ min. The moment of inertia of the wheel $J = 1$ kg·m^2. (a) Find the magnitude of retarding torque τ; (b) the number of the revolutions N of the wheel.

Case 3.5

3.5.1. A computer disk drive is turned on starting from rest and has a constant angular acceleration. If it took 0.50 s for the drive to make its second complete revolution, (a) how long did it take to make the first complete revolution, and (b) what is its angular acceleration, in rad/s^2?

3.5.2. A stone is suspended from the free end of a wire that is wrapped around the outer rim of a pulley , similar to what is shown in Fig. 3.4. The pulley is a uniform disk with mass 8.0 kg and radius 5.0 cm and turns on frictionless bearings. You measure that the stone travels 1.125 m within the first 3.00 s starting from rest. Find (a) the acceleration of the stone, (b) the tension in the wire and, (c) the mass of the stone.

3.5.3. Under some circumstances, a star can collapse into an extremely dense object made mostly of neutrons and called a neutron star. The density of a neutron star is roughly 10^{14} times as great as that of ordinary solid matter. Suppose the star is a uniform solid

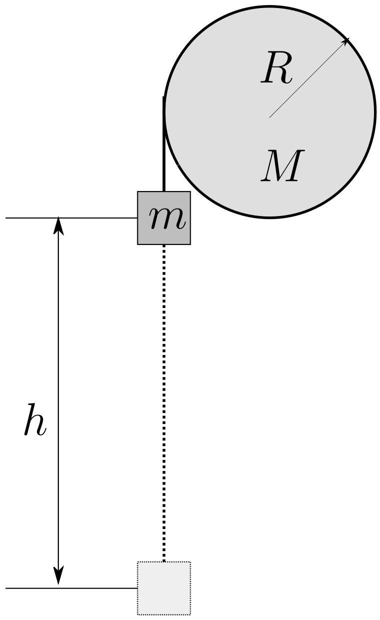

Figure 3.4. Problem 3.5.2

rigid sphere, both before and after the collapse. Its initial radius was $7.0 \cdot 10^5$ km (comparable to our Sun); its final radius is about 14 km. If the original star rotated once in 30 days, estimate the angular speed of the neutron star.

3.5.4. A flywheel is rotated with a constant angular velocity by an engine. The power of the engine was turned off. Once started, the flywheel made $N = 120$ revolutions during $t = 30$ s and stopped. The moment of inertia of the flywheel $J = 0.3$ kg·m^2. The angular acceleration of the flywheel is constant after the engine has stopped. Find (a) the torque developed by the engine and (b) the rotation frequency when the flywheel rotates uniformly.

3.5.5. In a homogeneous disk of the mass $m_1 = 1$ kg and radius $R = 30$ cm, a round aperture is cut of the radius $r = 10$ cm. Its center is at the distance $l = 15$ cm from the axis of the disk. Find the moment of inertia of the disk about the axis which passes perpendicular to its surface through the center of the disk.

Chapter 4

WORK AND ENERGY CONSERVATION LAW

Equation number	Equation	Equation title	Comments
1	2	3	4
4.1	$\delta W = \vec{\boldsymbol{F}}(\vec{\boldsymbol{r}}) \cdot d\vec{\boldsymbol{r}}$	Infinitesimal mechanical work	$\vec{\boldsymbol{F}}$ is a force vector; $d\vec{\boldsymbol{r}}$ is an infinitesimal displacement vector
4.2	$W_{if} = \int\limits_L \vec{\boldsymbol{F}}(\vec{\boldsymbol{r}}) \cdot d\vec{\boldsymbol{r}}$	General definition of work (linear integral)	L is a trajectory of the motion from the initial position i to the final position f
4.3	$W = F\, s \cos\phi$	Work done by the constant force under straight line motion	s is a pathway of the particle; ϕ is an angle between the direction of the force and the displacement
4.4	$P = \dfrac{\delta W}{dt} = \vec{\boldsymbol{F}} \cdot \vec{\boldsymbol{v}}$	Power in translational motion	δW is work done during the time dt, $\vec{\boldsymbol{v}}$ is a velocity of the particle

1	2	3	4
4.5	$K_E = \dfrac{mv^2}{2} = \dfrac{p^2}{2m}$	Kinetic energy of a particle's translational motion	m, v, p are mass, speed, and momentum of the particle
4.6	$W_{if}^{Tot} = K_{E_f} - K_{E_i}$	Work–Kinetic Energy Theorem	W_{if}^{Tot} is the total work done; $K_{E_{f,i}}$ is a $f$inal/$i$nitial kinetic energy of the system
4.7	$U = \dfrac{kx^2}{2}$	Potential energy of a deformed spring	x is a deformation; k is a spring constant
4.8	$U = -G\dfrac{m_1 m_2}{r}$	Potential energy of gravitational interaction of the particles	m_1, m_2 are masses of the interacting particles; r is a distance between them; G is a gravitational constant
4.9	$U = mgh$	Gravitational potential energy	h is a height; m is the mass of the body
4.10	$W_{if}^{Con} = U_i - U_f$	Potential Energy Theorem	W_{if}^{Con} is the work done by conservative forces; $U_{i,f}$ is an $i$nitial/$f$inal potential energy of the system

1	2	3	4
4.11	$\vec{\boldsymbol{F}} = -\operatorname{grad} U = -\vec{\boldsymbol{\nabla}} U = -\left(\frac{\partial U}{\partial x}\vec{\boldsymbol{i}} + \frac{\partial U}{\partial y}\vec{\boldsymbol{j}} + \frac{\partial U}{\partial z}\vec{\boldsymbol{k}}\right)$	Relation between a potential energy and a force	$\vec{\boldsymbol{i}}$, $\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{k}}$ are unit vectors
4.12	$\vec{\boldsymbol{F}} = -\frac{dU}{dr}\frac{\vec{\boldsymbol{r}}}{r}$	Relation between a potential energy and a central force	$\vec{\boldsymbol{r}}$ is a position vector
4.13	$E = K_E + U = \text{const}$	Mechanical energy conservation law	E is a total mechanical energy; K_E is a kinetic energy; U is a potential energy
4.14	$\delta W = \vec{\boldsymbol{\tau}} \cdot d\vec{\boldsymbol{\theta}}$	Infinitesimal work under rotational motion	$\vec{\boldsymbol{\tau}}$ is a torque; $d\vec{\boldsymbol{\theta}}$ is an infinitesimal angle of rotation
4.15	$P = \vec{\boldsymbol{\tau}} \cdot \vec{\boldsymbol{\omega}}$	Power in rotational motion	$\vec{\boldsymbol{\omega}}$ is an angular velocity vector
4.16	$K_E = \frac{J\omega^2}{2}$	Rotational kinetic energy	J is a moment of inertia about the axis of rotation; ω is an angular speed

Pre-Class Reading: [1] *chap.* 6 — 8; [2] *chap.* 6 — 8; [3] *chap.* 7 — 9.

Case 4.1

4.1.1. A tow truck pulls a car 1.00 km along a horizontal roadway using a cable having a tension of 800 N. (a) How much work does the cable do on the car if it pulls horizontally? If it pulls at 30.0° above the horizontal? (b) How much work does the cable do on the tow truck in both cases of part (a)? (c) How much work does gravity do on the car in part (a)?

4.1.2. A car is stopped in a distance d by a constant friction force that is independent of the car's speed. What is the stopping distance (in terms of d) (a) if the car's initial speed is double, and (b) if the speed is the same as it originally was but the friction force is doubled? (Solve using the work-energy theorem.)

4.1.3. A 70-kg swimmer jumps into the swimming pool from a diving board 3.20 m above the water. Use energy conservation law to find his speed just he hits the water (a) if he just holds his nose and drops in, (b) if he bravely jumps straight up (but just beyond the board!) at 4.00 m/s, and (c) if he manages to jump downward at 4.00 m/s.

4.1.4. The potential energy function for a system of particles is given by $U(x) = -x^3 + 4x^2 + 3x$, where x is the position of one particle in the system. (a) Determine the force F_x on the particle as a function of x. (b) For what values of x is the force equal to zero? (c) Plot $U(x)$ versus x and F_x versus x and indicate points of stable and unstable equilibrium.

4.1.5. A waterfall of height 50 m has $12 \cdot 10^3$ m^3 of water falling every minute. If the waterfall is used to produce electricity in a power station and the efficiency of conversation of kinetic energy of falling water to electrical energy is 50 %, what is the power production of the station. (The mass density of water is 10^3 kg/m^3.)

Case 4.2

4.2.1. A force $\vec{\boldsymbol{F}} = (-5x\vec{\boldsymbol{i}} + 2y\vec{\boldsymbol{j}})$, where $\vec{\boldsymbol{F}}$ is in newtons and x and y are in meters, acts on an object as the object moves in the y-direction from the origin to $y = -7.00$ m. Find the work done by the force on the object.

4.2.2. A soccer ball with mass 0.400 kg is initially moving with speed 4.00 m/s. A soccer player kicks the ball, exerting a constant force of magnitude 50.0 N in the same direction as the ball's motion. Over what distance must the player's foot be in contact with the ball to increase the ball's speed to 6.00 m/s?

4.2.3. Tarzan, in one tree, sees Jane in another tree. He grabs the end of a vine with length 20 m that makes an angle of 45° with the vertical, steps off his tree limb, and swings down and then up to Jane's open arms. When he arrives, his vine makes an angle of 30° with the vertical. Determine whether he gives her a tender embrace or knocks her off her limb by calculating Tarzan's speed just before he reaches Jane. You can ignore air resistance and the mass of the vine.

4.2.4. A potential energy function for a system in which a three-dimensional force acts is of the form $U = -\frac{\alpha}{r}$, where $r = \sqrt{x^2 + y^2 + z^2}$ and α is a constant value. Find the force that acts at the point determined by position vector $\vec{\boldsymbol{r}} = x\vec{\boldsymbol{i}} + y\vec{\boldsymbol{j}} + z\vec{\boldsymbol{k}}$.

4.2.5. A block of mass 0.20 kg is placed on top of a light, vertical spring of force constant 4 kN/m and pushed downward so that the spring is compressed by 0.05 m. After the block is released from rest, it travels upward and then leaves the spring. To what maximum height above the point of release does it rise?

Case 4.3

4.3.1. The mass of a proton is 1836 times the mass of an electron. (a) A proton is traveling at speed v_p. At what speed (in terms of v_p) would an electron have the same kinetic energy as the proton? (b) An electron has kinetic energy K_e. If a proton has the same momentum as the electron, what is its kinetic energy (in terms of K_e)? (c) If a proton in part (b) has the same speed as the electron, what is its kinetic energy (in terms of K_e)?

4.3.2. A 2.00-kg block of ice is placed against a horizontal spring that has force constant $k = 200$ N/m and is compressed 0.04 m. The spring is released and accelerates the block along a horizontal surface. You can ignore friction and the mass of the spring. (a) Calculate the work done on the block by the spring during the motion of the block from its initial position to where the spring has returned to its uncompressed length. (b) What is the speed of the block after it leaves the spring?

4.3.3. A 0.40-kg stone is held 0.5 m above the top edge of a water well and then dropped into it. The well has a depth of 4.5 m. Relative to the configuration with the stone at the top edge of the well, what is the gravitational potential energy of the stone–Earth system (a) before the stone is released and (b) when it reaches the bottom of the well? (c) What is the change in gravitational potential energy of the system from release to reaching the bottom of the well?

4.3.4. The engine delivers 150 kW to an aircraft propeller at 2400 rev/min. (a) How much torque does the aircraft engine provide? (b) How much work does the engine do in one revolution of the propeller?

4.3.5. A billiard ball moving at $v_0 = 5.0$ m/s collides with another

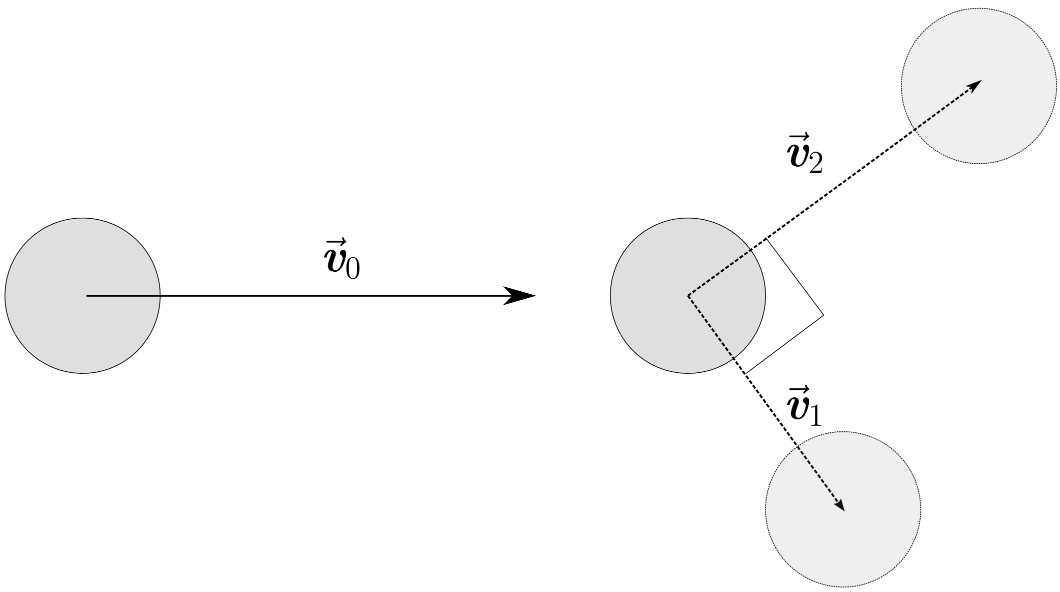

Figure 4.1. Problem 4.3.5

billiard ball at rest, as shown in Fig. 4.1. The balls move off at right angles to one another. If the first ball continues with a speed of $v_1 =$

3.0 m/s, what is the speed v_2 of the ball that was initially at rest?

Case 4.4

4.4.1. You throw a 10-N rock vertically into the air from ground level. You observe that when it is 20.0 m above the ground, it is traveling at 15.0 m/s upward. Use the work-energy theorem to find (a) the rock's speed just as it left the ground and (b) its maximum height.

4.4.2. A 10.0-kg rock is sliding on a rough, horizontal surface at 4.00 m/s and eventually stops due to friction. The coefficient of kinetic friction between the rock and the surface is 0.150. What average power is produced by friction as the rock stops?

4.4.3. Astronomers discover a meteorite moving directly toward the Earth with velocity of 1 km/s. The distance from meteorite to the center of the Earth is equal to 16 times radius of the Earth. Estimate the velocity of the meteorite when it hits the Earth's surface. Ignore all drag effects.

4.4.4. A single conservative force acting on a particle within a system varies as $\vec{\boldsymbol{F}} = -2(ax + 2bx^3)\vec{\boldsymbol{i}}$, where a and b are constants, $\vec{\boldsymbol{F}}$ is in newtons, and x is in meters. (a) Calculate the potential energy function $U(x)$ associated with this force for the system, taking $U = 0$ at $x = 0$. Find (b) the change in potential energy and (c) the change in kinetic energy of the system as the particle moves from $x = 1.00$ m to $x = 2.00$ m.

4.4.5. A light rope is 0.90 m long. Its top end is pivoted on a frictionless, horizontal axle. The rope hangs straight down at rest with a small, massive ball attached to its bottom end. You strike the ball, suddenly giving it a horizontal velocity so that it swings around in a full circle. What minimum speed at the bottom is required to make the ball go over the top of the circle?

Case 4.5

4.5.1. A boy in a wheelchair (total mass 50.0 kg) has a speed of

1.50 m/s at the crest of a slope 2.50 m high and 12.5 m long. At the bottom of the slope, his speed is 6.50 m/s. Assume air resistance and rolling resistance can be modeled as a constant friction force of 40.0 N. Find the work he did in pushing forward on his wheels during the downhill ride.

4.5.2. A toy cannon uses a spring to project a 5.0-g soft rubber ball. The spring is originally compressed by 5.00 cm and has a force constant of 10.0 N/m. When the cannon is fired, the ball moves 10.0 cm through the horizontal barrel of the cannon, and the barrel exerts a constant friction force of 0.025 N on the ball. (a) With what speed does the projectile leave the barrel of the cannon? (b) At what point does the ball have maximum speed? (c) What is this maximum speed?

4.5.3. An electric scooter has a battery capable of supplying 0.150 kWh of energy. If friction forces and other losses account for 50.0% of the energy usage, what altitude change can a rider achieve when driving in a hilly terrain if the rider and the scooter have a combined weight of 900 N?

4.5.4. A 600-kg elevator starts from rest. It moves upward for 2.00 s with a constant acceleration until it reaches its cruising speed of 2.00 m/s. (a) What is the average power of the elevator motor during this time interval? (b) How does this power compare with the motor power when the elevator moves at its cruising speed?

4.5.5. What is the minimum speed (relative to Earth) required for a rocket to send it out of the solar system? Note that you need to take use of Earth's speed to arrive at your result.

Chapter 5
MECHANICAL OSCILLATIONS AND WAVES

Equation number	Equation	Equation title	Comments
1	2	3	4
5.1	$T = \frac{t}{N}$; $f = \frac{1}{T}$	Period T and frequency of oscillations f	N is a number of oscillations per time t
5.2	$\omega = 2\pi f$	Angular frequency of oscillations	
5.3	$\frac{d^2x}{dt^2} + \omega_0^2 x = 0$	Differential equation of simple harmonic oscillations	ω_0 is an angular frequency of undamped oscillations
5.4	$x = A\cos(\omega t + \varphi_0)$	Position under harmonic oscillations	x is a displacement from equilibrium position; A is an amplitude of oscillations; φ_0 is an initial phase of oscillations
5.5	$T = 2\pi\sqrt{\frac{l}{g}}$	Period of a simple pendulum	l is a the length of the pendulum

1	2	3	4
5.6	$T = 2\pi\sqrt{\dfrac{m}{k}}$	Period of a spring-mass oscillator	k is a spring constant; m is a mass of the load
5.7	$T = 2\pi\sqrt{\dfrac{J}{mgl}}$	Period of a physical pendulum	J is a moment of inertia of a body about the axis of rotation; l is a distance between the pivot and the center of mass
5.8	$\dfrac{d^2x}{dt^2} + 2\beta\dfrac{dx}{dt} + \omega_0^2 x = 0$	Differential equation of free damped oscillations	$\beta = \dfrac{r}{2m}$ is a damping coefficient; r is a linear drag (resistance) coefficient
5.9	$x = A_0 \exp^{-\beta t} \times \cos(\omega t + \varphi_0)$	Displacement of under-damped oscillations	$\omega = \sqrt{\omega_0^2 - \beta^2}$ is an angular frequency of damped oscillations
5.10	$\omega_0 = \beta$	Condition for critical damping	ω_0 is a natural oscillation frequency
5.11	$\dfrac{d^2x}{dt^2} + 2\beta\dfrac{dx}{dt} + \omega_0^2 x = \dfrac{F_0}{m}\cos(\Omega t)$	Differential equation of driven oscillations	F_0 is an amplitude of a driving force; Ω is an angular frequency of a driving force
5.12	$x = A(\Omega)\cos(\Omega t - \phi_d)$	Displacement of driven oscillations	ϕ_d is a phase shift of driven oscillations

1	2	3	4
5.13	$A(\Omega) = \dfrac{F_0/m}{\sqrt{(\Omega^2-\omega_0^2)^2+4\beta^2\Omega^2}}$	Amplitude of driven oscillations	ω_0 is an angular frequency of undamped oscillations
5.14	$\tan\phi_d = \dfrac{2\beta\Omega}{\Omega^2-\omega_0^2}$	Phase shift of driving oscillations	β is a damping coefficient
5.15	$\dfrac{\partial^2\xi}{\partial t^2} = v^2\dfrac{\partial^2\xi}{\partial x^2}$	Wave equation	v is a propagation speed of a wave
5.16	$\xi(x,t) = A\cos(\omega t - kx + \varphi_0)$, $k = 2\pi/\lambda$	Equation of a plane harmonic wave with the wavenumber k	$\xi(x,t)$ is a displacement of a particle at the position x at the time t; λ is a wavelength
5.17	$v = \lambda f = \omega/k$	Propagation speed of a wave	f is a frequency of oscillations
5.18	$v_\perp = \sqrt{\dfrac{F}{\mu}}$	Propagation speed of a transversal wave on a string	F is a string tension force; μ is a linear mass density
5.19	$v_\parallel = \sqrt{\dfrac{E}{\rho}}$	Propagation speed of a longitudinal wave in an elastic medium	E is Young's module; ρ is a mass density of the medium
5.20	$v = \sqrt{\dfrac{\gamma P}{\rho}}$	Propagation speed of a sound wave in gases	γ is an adiabatic index; P is a gas pressure; ρ is a mass density of a gas

1	2	3	4
5.21	$\langle w \rangle = \frac{1}{2}\rho A^2\omega^2$	Average wave energy density	A is an amplitude of the wave; ω is angular frequency; ρ is a mass density of the medium
5.22	$\vec{\boldsymbol{j}} = \langle w \rangle \vec{\boldsymbol{v}}$	Vector of an energy flux density	$\vec{\boldsymbol{v}}$ is a propagation velocity vector

Pre-Class Reading: [1] *chap.* 13&15; [2] *chap.* 13&14; [3] *chap.* 15&16.

Case 5.1

5.1.1. This procedure has actually been used to "weigh" astronauts in space. A 45.0-kg chair is attached to a spring and allowed to oscillate. When it is empty, the chair takes 1.50 s to make one complete vibration. But with an astronaut sitting in it, with his feet off the floor, the chair takes 2.50 s for one cycle. What is the mass of the astronaut?

5.1.2. A 0.32-kg toy is undergoing SHM on the end of a horizontal spring with force constant $k = 200$ N/m. When the object is 0.10 m from its equilibrium position, it is observed to have a speed of 0.50 m/s. What are (a) the total energy of the object at any point of its motion; (b) the amplitude of the motion; (c) the maximum speed attained by the object during its motion?

5.1.3. A mass on spring with a natural angular frequency $\omega_0 = 1.3$ rad/s is placed in an environment in which there is a damping force proportional to the speed of the mass. If the amplitude is reduced to 36.8 % its initial value in 2.0 s, what is the angular frequency of the damped motion?

5.1.4. A mass of 1.5 kg is suspended from a spring, which stretches by 10 cm. The support from which the spring is suspended is set into sinusoidal motion. At what frequency would you expect resonant behavior?

5.1.5. The wave equation for a particular wave is

$$y(x,t) = 4.0 \sin\left(\frac{\pi(x-400t)}{2}\right).$$

All values are in appropriate SI units. What is the (a) amplitude; (b) wavelength; (c) frequency; (d) and propagation speed of the wave?

Case 5.2

5.2.1. When a 0.650-kg mass oscillates on an ideal spring, the frequency is 6.30 Hz. (a) What will the frequency be if 0.160 kg are added to the original mass, and (b) subtracted from the original mass? Try to solve this problem *without* finding the force constant of the spring.

5.2.2. You are watching an object that is moving in SHM. When the object is displaced 0.800 m to the right of its equilibrium position, it has a velocity of 1.50 m/s to the right and an acceleration of 5.00 m/s^2 to the left. How much farther from this point will the object move before it stops momentarily and then starts to move back to the left?

5.2.3. The damping coefficient of a damped harmonic oscillator can be adjusted. Two measurements are made. First, when the damping coefficient is zero, the angular frequency of motion is 4000 rad/s. Second, a static measurement shows that the effective spring constant of the system is 200 N/m. To what value should the linear drag coefficient be set in order to have critical damping?

5.2.4. Consider the driven, damped harmonic motion with natural oscillation frequency ω_0 and damping coefficient β. Determine resonant frequency of the system. Resonance occurs when the amplitude has a maximum as a function of driven frequency.

5.2.5. One end of a horizontal rope is attached to a prong of an electrically driven tuning fork that vibrates the rope transversely at 440 Hz. The other end passes over a pulley and supports a 2.00-kg mass. The linear mass density of the rope is 0.050 kg/m. (a) What is the speed of a transverse wave on the rope? (b) What is the wavelength? (c) How would your answers to parts (a) and (b) change if the mass were decreased to 0.50 kg?

Case 5.3

5.3.1. A 3.00-kg mass on a spring has displacement as a function of time given by the equation

$$x(t) = (8.00 \text{ cm}) \cos\left[(6\text{s}^{-1})t - \pi/2\right].$$

Find (a) the time for one complete vibration; (b) the force constant of the spring; (c) the maximum speed of the mass; (d) the maximum force on the mass; (e) the position, speed, and acceleration of the mass at $t = 1.047$ s; (f) the force on the mass at that time.

5.3.2. A 0.400-kg glider, attached to the end of an ideal spring with force constant $k = 250$ N/m, undergoes SHM with an amplitude of 0.050 m. Compute (a) the maximum speed of the glider; (b) the speed of the glider when it is at $x = -0.03$ m; (c) the magnitude of the maximum acceleration of the glider; (d) the acceleration of the glider at $x = -0.03$ m; (e) the total mechanical energy of the glider at any point in its motion.

5.3.3. A harmonic oscillator with natural period $T = 6.283$ s is placed in an environment where its motion is damped, with a damping force proportional to its speed. The amplitude of the oscillation drops to 95 percent of its original value in 0.5 s. What is the period of the oscillator in the new environment?

5.3.4. A 2.00-kg object attached to a spring moves without friction and is driven by an external force given by the expression $F = 8.00 \sin(3t)$, where F is in newtons and t is in seconds. The force constant of the spring is 50.0 N/m. Find (a) the resonance angular frequency of the system, (b) the angular frequency of the driven system, and (c) the amplitude of the motion.

5.3.5. On December 26, 2004, a great earthquake occurred off the coast of Sumatra and triggered immense waves (tsunami) that killed some 200,000 people. Satellites observing these waves from space measured 800 km from one wave crest to the next and a period between waves of 1.0 hour. What was the speed of these waves in m/s and km/h? Does your answer help you understand why the waves caused such devastation?

Case 5.4

5.4.1. A 1.50-kg, frictionless block is attached to an ideal spring with force constant 600 N/m. At $t = 0$ the spring is neither stretched nor compressed and the block is moving in the positive direction at 8.0 m/s. Find (a) the amplitude and (b) the phase angle. (c) Write an equation for the position as a function of time.

5.4.2. A harmonic oscillator has angular frequency ω and amplitude A. (a) What are the magnitudes of the displacement and velocity when the elastic potential energy is equal to the kinetic energy? (Assume that $U = 0$ at equilibrium.) (b) How often does this occur in each cycle? What is the time between occurrences? (c) At an instant when the displacement is equal to $A/2$, what fraction of the total energy of the system is kinetic and what fraction is potential?

5.4.3. A spring and an attached bob oscillates in viscous medium

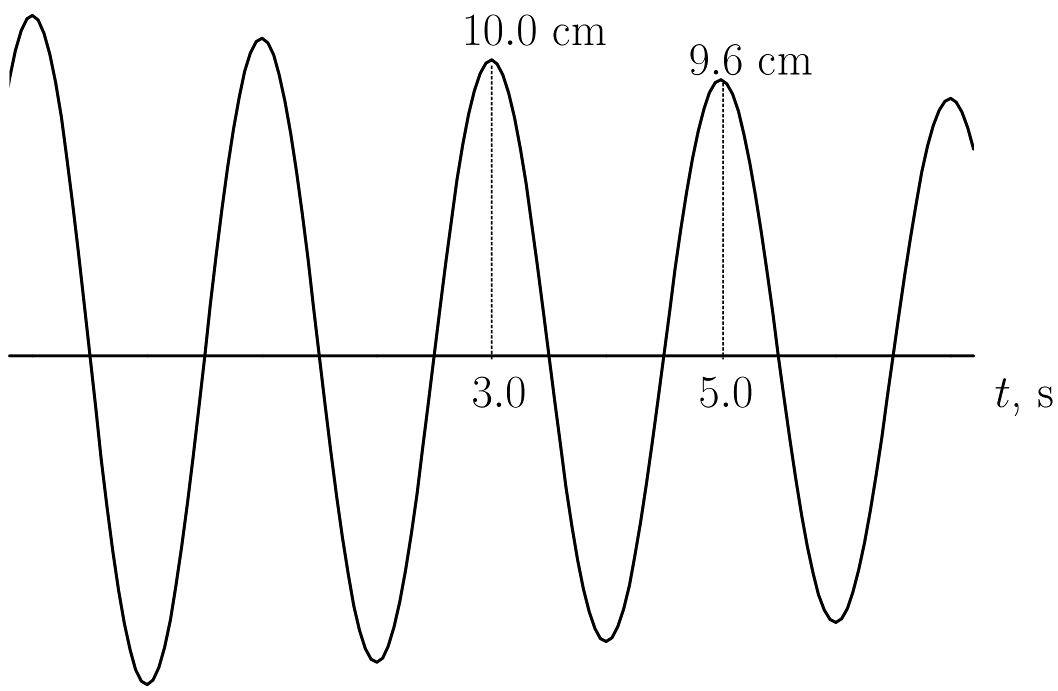

Figure 5.1. Problem 5.4.3

(Fig. 5.1). A given maximum, of +10.0 cm from the equilibrium position, is observed at $t = 3.0$ s, and the next maximum, of +9.6 cm, occurs at $t = 5.0$ s. (a) What is the angular oscillation frequency of the system? (b) What is the damping coefficient of the system? (c) What will the position of the bob be at 6 s? (d) What is the position at $t = 0$ s?

5.4.4. A block weighing 30.0 N is suspended from a spring that has a force constant of 300 N/m. The system is undamped and is subjected to a harmonic driving force of frequency 1.00 Hz, resulting in a forced-motion amplitude of 5.00 cm. Determine the maximum value of the driving force.

5.4.5. A piano wire with mass 2.00 g and length 80.0 cm is stretched with a tension of 36.0 N. A wave with frequency 150.0 Hz and amplitude 1.0 mm travels along the wire. (a) Calculate the average power carried by the wave. (b) What happens to the average power if the wave amplitude is doubled?

Case 5.5

5.5.1. A 250-g block is attached to a horizontal spring and executes simple harmonic motion with a period of 0.314 s. The total energy of the system is 8.00 J. Find (a) the force constant of the spring and (b) the amplitude of the motion.

5.5.2. A ball of mass m is connected to two rubber bands of length

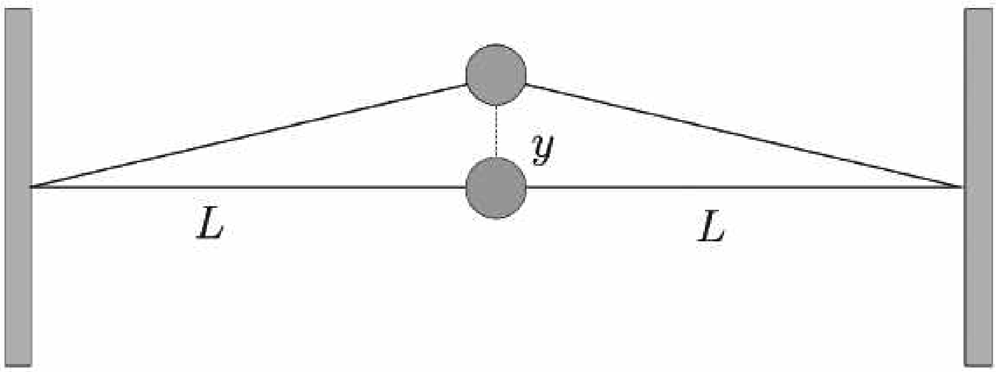

Figure 5.2. Problem 5.5.2

L, each under tension T as shown in Fig. 5.2. The ball is displaced by a small distance y perpendicular to the length of the rubber bands. Assuming the tension does not change, find (a) the restoring force and (b) the angular oscillation frequency of the system.

5.5.3. A 10.-kg object oscillates at the end of a vertical spring that has a spring constant of $2.5 \cdot 10^4$ N/m. The effect of air resistance is represented by the damping coefficient $b = 2.00$ N·s/m. (a) Calculate the frequency of the damped oscillation. (b) By what percentage does the amplitude of the oscillation decrease in each cycle? (c) Find the time interval that elapses while the energy of the system drops to 1.00% of its initial value.

5.5.4. A particular spring has a spring constant of 76 N/m and a mass of 0.5 kg at its end. When the spring is driven in a viscous medium, the resonant motion occurs at an angular frequency of 12 rad/s. What is (a) the damping coefficient of the system? (b) the linear drag coefficient due to the viscous medium?

5.5.5. The speed of sound in air at 24°C is 345 m/s. (a) What is the wavelength of a sound wave with a frequency of 880 Hz, corresponding to the note A_5 on a piano, and how many milliseconds does each vibration take? (b) What is the wavelength of a sound wave one octave lower than the note in part (a)?

Chapter 6
MOLECULAR PHYSICS AND IDEAL GAS LAW

Equation number	Equation	Equation title	Comments
1	2	3	4
6.1	$PV = \nu RT$	Ideal gas law	P is a pressure of the gas; V is a volume; ν is a number of moles of a substance; R is a universal gas constant; T is an absolute temperature
6.2	$P = nk_{B}T$	Pressure of an ideal gas	n is a number density of particles; k_{B} is the Boltzmann's constant
6.3	$P = \frac{2}{3}n\langle\varepsilon\rangle = \frac{1}{3}nm\langle v^2\rangle$	The main equation of a kinetic theory of gases	$\langle\varepsilon\rangle = \frac{3}{2}k_{B}T$ is an average kinetic energy of a translational motion of the molecule with the mass m

1	2	3	4
6.4	$\langle\varepsilon\rangle = \frac{i}{2}k_B T$	Equipartition energy theorem	$\langle\varepsilon\rangle$ is an average kinetic energy of the molecules; i is a number of degrees of freedom
6.5	$f(v) = \frac{dN}{Ndv} = Av^2 e^{-\frac{mv^2}{2k_B T}}$; $A = 4\pi\left(\frac{m}{2\pi k_B T}\right)^{\frac{3}{2}}$	Maxwell–Boltzmann speed distribution function	dN is a number of molecules with speed from v to $v + dv$; N is a total number of molecules
6.6	$v_{\text{rms}} = \sqrt{\langle v^2\rangle} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{\mu}}$	Root mean square speed of the molecules	m is a mass of the molecule
6.7	$v_{\text{mp}} = \sqrt{\frac{2RT}{\mu}}$	The most probable speed of the molecules	
6.8	$\langle v\rangle = \sqrt{\frac{8RT}{\pi\mu}}$	The average speed of the molecules	
6.9	$P(z) = P_0 e^{-\frac{\mu g z}{RT}}$	Barometric formula	$P(z)$ is a pressure at the height z; P_0 is a pressure at sea level

1	2	3	4
6.10	$n(z) = n_0 e^{-\frac{mgz}{k_B T}} = n_0 e^{-\frac{\mu g z}{RT}}$	Law of atmosphere	n_0 is a number density of molecules at sea level; z is a height

Pre-Class Reading: [1] *chap.* 18; [2] *chap.* 19; [3] *chap.* 21.

Case 6.1

6.1.1. Helium gas with a volume of 2.60 L, under a pressure of 1.30 atm and at a temperature of 41.0°C, is warmed until both pressure and volume are doubled. (a) What is the final temperature? (b) How many grams of helium are there? The molar mass of helium is 4.00 g/mol.

6.1.2. Three moles of an ideal gas are in a rigid cubical box with sides of length 0.200 m. (a) What is the force that the gas exerts on each of the six sides of the box when the gas temperature is 20.0°C? (b) What is the force when the temperature of the gas is increased to 100.0°C?

6.1.3. Two gases in a mixture diffuse through a filter at rates proportional to their rms speeds. (a) Find the ratio of speeds for the two isotopes of chlorine, ^{35}Cl and ^{37}Cl, as they diffuse through the air. (b) Which isotope moves faster?

6.1.4. Consider an ideal gas at 27°C and 1.00 atm pressure. To get some idea how close these molecules are to each other, on the average, imagine them to be uniformly spaced, with each molecule at the center of a small cube. (a) What is the length of an edge of each cube if adjacent cubes touch but do not overlap? (b) How does this distance compare with the diameter of a typical molecule? (c) How does their separation compare with the spacing of atoms in solids, which typically are about 0.3 nm apart?

6.1.5. Assume the Earth's atmosphere has a uniform temperature of 17.0°C and uniform composition, with an effective molar mass of 29 g/mol. Jetliners cruise at an altitude about 8.31 km. Find the ratio of the atmospheric density there to the density at sea level.

Case 6.2

6.2.1. A cylindrical tank has a tight-fitting piston that allows the volume of the tank to be changed. The tank originally contains 0.15 m^3 of air at a pressure of 2.40 atm. The piston is slowly pulled out until the volume of the gas is increased to 0.360 m^3. If the temperature remains constant, what is the final value of the pressure?

6.2.2. A cylinder contains 0.10 mol of an ideal monatomic gas. Initially the gas is at a pressure of $1.00 \cdot 10^5$ Pa and occupies a volume of $2.50 \cdot 10^{-3}$ m^3. (a) Find the initial temperature of the gas in kelvins. (b) If the gas is allowed to expand to twice the initial volume, find the final temperature (in kelvins) and pressure of the gas if the expansion is (i) isothermal; (ii) isobaric.

6.2.3. Modem vacuum pumps make it easy to attain pressures of the order of 10^{-13} atm in the laboratory. (a) At a pressure of $9.00 \cdot 10^{-14}$ atm and an ordinary temperature of 300.0 K how many molecules are present in a volume of 1.00 cm^3? (b) How many molecules would be present at the same temperature but at 1.00 atm instead?

6.2.4. Consider a container of nitrogen gas molecules at 900 K. Calculate (a) the most probable speed, (b) the average speed, and (c) the rms speed for the molecules.

6.2.5. A flask contains a mixture of neon ($_{10}$Ne), krypton ($_{36}$Kr), and radon ($_{86}$Rn) gases. Compare (a) the average kinetic energies of the three types of atoms and; (b) the root-mean-square speeds.

Case 6.3

6.3.1. A cylinder contains a mixture of helium and argon gas in equilibrium at 150°C. (a) What is the average kinetic energy for each type of gas molecule? (b) What is the rms speed of each type of molecule?

6.3.2. The total lung volume for a typical physics student is 6.00 L. A physics student fills her lungs with air at an absolute pressure of 1.00 atm. Then, holding her breath, she compresses her chest cavity, decreasing her lung volume to 5.70 L. What is the pressure of the air in her lungs then? Assume that the temperature of the air remains constant.

6.3.3. (a) How many atoms of helium gas fill a spherical balloon of diameter 30.0 cm at 20.0°C and 1.00 atm? (b) What is the average kinetic energy of the helium atoms? (c) What is the rms speed of the helium atoms?

6.3.4. In a gas at standard conditions, what is the length of the side of a cube that contains a number of molecules equal to the population of the Earth (about $7 \cdot 10^9$ people)?

6.3.5. At what temperature is the root-mean-square speed of oxygen molecules equal to the root-mean-square speed of hydrogen molecules at 27.0°C?

Case 6.4

6.4.1. A 2.00-mol sample of oxygen gas is confined to a 5.00-L vessel at a pressure of 8.00 atm. Find the average translational kinetic energy of the oxygen molecules under these conditions.

6.4.2. A diver observes a bubble of air rising from the bottom of a lake (where the absolute pressure is 3.50 atm) to the surface (where the pressure is 1.00 atm). The temperature at the bottom is 4.0°C, and the temperature at the surface is 23.0°C. (a) What is the ratio of the volume of the bubble as it reaches the surface to its volume at the bottom? (b) Would it be safe for the diver to hold his breath while ascending from the bottom of the lake to the surface? Why or why not?

6.4.3. The rms speed of an oxygen molecule (O_2) in a container of oxygen gas is 625 m/s. What is the temperature of the gas?

6.4.4. How many moles are in a 1.00-kg bottle of water? How many molecules? The molar mass of water is 18.0 g/mol.

6.4.5. Smoke particles in the air typically have masses of the order of 10^{-16} kg. The Brownian motion (rapid, irregular movement) of these particles, resulting from collisions with air molecules, can be observed with a microscope. (a) Find the root-mean-square speed of Brownian motion for a particle with a mass of $3.00 \cdot 10^{-16}$ kg in air at 300 K. (b) Would the root-mean-square speed be different if the particle were in hydrogen gas at the same temperature? Explain.

Case 6.5

6.5.1. Given that the molecular weight of water (H_2O) is 18 g/mol and that the volume occupied by 1.0 g of water is 10^{-6} m^3, use Avogadro's number to find the distance between neighboring water molecules. Assume for simplicity that the molecules stacked like cubes.

6.5.2. The pressure of an ideal gas in a closed container is 0.60 atm at 35°C. The number of molecules is $5.0 \cdot 10^{22}$. (a) What are the pressure in pascals and the temperature in kelvins?(b) What is the volume of the container? (c) If the container is heated to 120°C, what is the pressure in atmospheres?

6.5.3. Use the ideal gas law to calculate the volume occupied by 1 mol of ideal gas at 1 atm pressure and 0°C. Given that the average molecular weight of air is 28.9 g/mol, calculate the mass density of air, in kg/m^3, at the above conditions.

6.5.4. The rms speed of 1 mol of argon atoms (atomic weight 40 g/mol) in a box is 680 m/s. (a) What is the temperature inside the box? (b) If the box has a volume of 1 L, what is the pressure? Treat the gas as ideal.

6.5.5. If the rms speed of molecules of gaseous H_2O is 200 m/s, what will be the rms speed of CO_2 molecules at the same temperature? Assume that both of these are an ideal gas.

Chapter 7
THERMODYNAMICS

Equation number	Equation	Equation title	Comments
1	2	3	4
7.1	$\delta Q = dU + \delta W$	The first law of thermodynamics	δQ and δW are infinitesimal amounts of heat supplied to the system and work done by the system, respectively; dU is a differential change in the internal energy of the system
7.2	$\delta W = PdV$	Infinitesimal amount of work done by a gas	P is a gas pressure; dV is a differential volume change
7.3	$C = \dfrac{\delta Q}{dT}$	Heat capacity of a body	dT is a differential temperature change

1	2	3	4
7.4	$U = N\langle\varepsilon\rangle = = \frac{m}{\mu}\frac{i}{2}RT = = \frac{m}{\mu}C_{\mathrm{V}}T$	Ideal gas internal energy	N is a number of molecules; $\langle\varepsilon\rangle$ is an average energy of the molecule; m is a gas mass; μ is a molar mass of the gas; C_V is a molar heat capacity under the constant volume
7.5	$c = \frac{C}{m}$	Specific heat capacity	C is a body heat capacity; m is a mass of a body
7.6	$C_\mu = \mu c = \frac{\mu}{m}C$	Molar heat capacity	
7.7	$C_V = \frac{\mu}{m}\left(\frac{\delta Q}{dT}\right)_V = = \frac{i}{2}R$	Molar heat capacity under constant volume	$\left(\frac{\delta Q}{dT}\right)_V = \left(\frac{dU}{dT}\right)_V$
7.8	$C_P = \frac{\mu}{m}\left(\frac{\delta Q}{dT}\right)_P = = \frac{i+2}{2}R$	Molar heat capacity under constant pressure	i is a number of degrees of freedom
7.9	$C_P = C_V + R$	Mayer's relation	Ideal gas only
7.10	$PV^\gamma = \mathrm{const}$; $TV^{\gamma-1} = \mathrm{const}$; $TP^{\frac{1-\gamma}{\gamma}} = \mathrm{const}$	Equation for an ideal gas adiabatic process	$\gamma = C_P/C_V$ is adiabatic index; $\gamma = \frac{i+2}{i}$; $i = \frac{2}{\gamma-1}$

1	2	3	4
7.11	$W = \frac{m}{\mu} RT \ln \frac{V_f}{V_i} = = \frac{m}{\mu} RT \ln \frac{P_i}{P_f}$	Work done by an ideal gas under constant temperature	P_i and P_f are initial and final pressure of the gas; V_i and V_f are initial and final volume occupied by the gas
7.12	$W = \frac{m}{\mu} C_V (T_i - T_f)$	Work done by an ideal gas in adiabatic process	T_i and T_f are initial and final temperature of the gas
7.13	$\eta = \frac{T_H - T_C}{T_H}$	Efficiency of Carnot cycle	T_H and T_C are temperature of the hot and cold reservoir, respectively
7.14	$\eta = \frac{\lvert Q_H \rvert - \lvert Q_C \rvert}{\lvert Q_H \rvert}$	Efficiency of the heat engine	Q_H and Q_C are heat transfered from the hot source and to the cold sink through working body, respectively
7.15	$\Delta S = \int\limits_i^f \frac{\delta Q}{T}$	Entropy change	$i$nitial and $f$inal state of the system

Pre-Class Reading: [1] *chap.* 17 & 19 & 20; [2] *chap.* 17 & 18 & 20; [3] *chap.* 19 & 20 & 22.

Case 7.1

7.1.1. (a) How much heat does it take to increase the temperature of 2.50 mol of a diatomic ideal gas by 30.0 K near room temperature if the gas is held at constant volume? (b) What is the answer to the question in part (a) if the gas is monatomic rather than diatomic?

7.1.2. Three moles of an ideal monatomic gas expand at a constant pressure of 2.50 atm; the volume of the gas changes from $3.20 \cdot 10^{-2}$ m^3 to $4.50 \cdot 10^{-2}$ m^3. (a) Calculate the initial and final temperatures of the gas. (b) Calculate the amount of work the gas does in expanding. (c) Calculate the amount of heat added to the gas. (d) Calculate the change in internal energy of the gas.

7.1.3. The engine of a Ferrari F355 F1 sport's car takes in air at 20.0°C and 1.00 atm and compresses it adiabatically to 0.0900 times the original volume. The air may be treated as an ideal gas with $\gamma = 1.40$. (a) Draw a PV–diagram for this process. (b) Find the final temperature and pressure.

7.1.4. A gasoline engine has a power output of 180 kW (about 241 hp). Its thermal efficiency is 28.0%. (a) How much heat must be supplied to the engine per second? (b) How much heat is discarded by the engine per second?

7.1.5. One kilogram of iron at 80°C is dropped into 0.5 L of water at 20°C. Given that the specific heat of water is 1 cal/(g·K) and that of iron 0.107 cal/(g·K), calculate (a) the final equilibrium temperature of the system and (b) the increase of entropy.

Case 7.2

7.2.1. Two perfectly rigid containers each hold ν moles of ideal gas, one being hydrogen (H_2) and other being neon (Ne). If it takes 100 J of heat to increase the temperature of the hydrogen by 2.50°C, by how many degrees will the same amount of heat raise the temperature of the neon?

7.2.2. The temperature of 0.150 mol of an ideal gas is held constant at 77.0°C while its volume is reduced to 25.0% of its initial volume. The initial pressure of the gas is 1.25 atm. (a) Determine the work done by the gas. (b) What is the change in its internal energy? (c) Does the gas exchange heat with its surroundings? If so, how much? Does the gas absorb or liberate heat?

7.2.3. During an adiabatic expansion the temperature of 0.450 mol of argon (Ar) drops from 50.0°C to 10.0°C. The argon may be treated as an ideal gas. (a) Draw a PV–diagram for this process. (b) How much work does the gas do? (c) What is the change in internal energy of the gas?

7.2.4. A Carnot engine whose high-temperature reservoir is at 620 K takes in 550 J of heat at this temperature in each cycle and gives up 335 J to the low-temperature reservoir. (a) How much mechanical work does the engine perform during each cycle? (b) What is the temperature of the low-temperature reservoir? (c) What is the thermal efficiency of the cycle?

7.2.5. One mole of an ideal gas expands at constant pressure from an initial volume of 250 cm^3 to a final volume of 650 cm^3. What is the change in entropy, assuming that the gas is monatomic?

Case 7.3

7.3.1. (a) Calculate the specific heat capacity at constant volume of water vapor, assuming the nonlinear triatomic molecule has three translational and three rotational degrees of freedom and that vibrational motion does not contribute. The molar mass of water is 18.0 g/mol. (b) The actual specific heat capacity of water vapor at low pressures is about 2000 J/(kg·K). Compare this with your calculation and comment on the actual role of vibrational motion.

7.3.2. A gas in a cylinder is held at a constant pressure of $2.30 \cdot 10^5$ Pa and is cooled and compressed from 1.70 m^3 to 1.20 m^3. The internal energy of the gas decreases by $1.40 \cdot 10^4$ J. (a) Find the work done by the gas. (b) Find the absolute value $|Q|$ of the heat flow into or out of the gas, and state the direction of the heat flow. (c) Does it matter whether the gas is ideal? Why or why not?

7.3.3. Propane gas (C_3H_8) behaves like an ideal gas with $\gamma = 1.127$. Determine the molar heat capacity at constant volume and the molar heat capacity at constant pressure.

7.3.4. A Carnot engine has an efficiency of 59% and performs 2.5×10^4 J of work in each cycle. (a) How much heat does the engine extract from its heat source in each cycle? (b) Suppose the engine exhausts heat at room temperature (20.0°C). What is the temperature of its heat source?

7.3.5. Calculate the change in entropy of the universe if 0.3 kg of water at 70°C is mixed with 0.2 kg of water at 15°C in a thermally insulted container. Specific heat of water is 4.2 J/(K·g)

Case 7.4

7.4.1. Six moles of an ideal gas are in a cylinder fitted at one end with a movable piston. The initial temperature of the gas is 27.0°C and the pressure is constant. As part of a machine design project, calculate the final temperature of the gas after it has done $1.75 \cdot 10^3$ J of work.

7.4.2. A system is taken from state a to state b along the three paths shown in Fig. 7.1. (a) Along which path is the work done by the system the greatest? The least? (b) If $U_b > U_a$, along which path is the absolute value $|Q|$ of the heat transfer the greatest? For this path, is heat absorbed or liberated by the system?

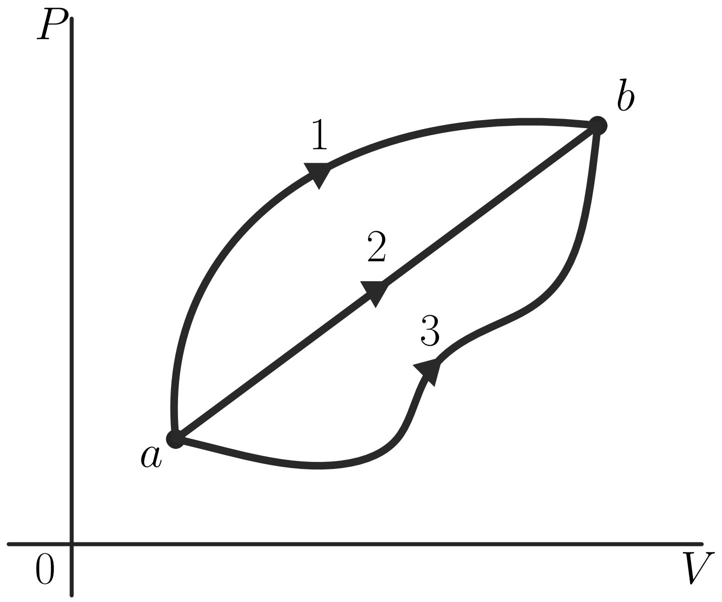

Figure 7.1. Problem 7.4.2

7.4.3. An experimenter adds 970 J of heat to 1.75 mol of an ideal gas to heat it from 10.0°C to 25.0°C at constant pressure. The gas does +223 J of work during the expansion. (a) Calculate the change in internal energy of the gas. (b) Calculate γ for the gas.

7.4.4. A Carnot heat engine has a thermal efficiency of 0.600, and the temperature of its hot reservoir is 800 K. If 3000 J of heat is rejected to the cold reservoir in one cycle, (a) what is the work output of the engine during one cycle? (b) What is the temperature of its cold reservoir?

7.4.5. A gas obeys the well-known equation of state $PV =$ (a constant)T. The gas expands, doubling in volume. (a) Plot P versus V when the expansion is isobaric and when it is isothermal. (b) What work is done by the gas on its surroundings for both cases above? (c) What is the entropy change of the gas for both cases above?

Case 7.5

7.5.1. Two moles of an ideal gas are compressed in a cylinder at a constant temperature of 85.0°C until the original pressure has tripled. (a) Sketch a PV–diagram for this process. (b) Calculate the amount of work done.

7.5.2. When a quantity of monatomic ideal gas expands at a constant pressure of $4.00 \cdot 10^4$ Pa, the volume of the gas increases from $2.00 \cdot 10^{-3}$ m^3 to $8.00 \cdot 10^{-3}$ m^3. What is the change in the internal energy of the gas?

7.5.3. A monatomic ideal gas that is initially at a pressure of $1.50 \cdot 10^5$ Pa and has a volume of 0.0800 m^3 is compressed adiabatically to a volume of 0.0400 m^3. (a) What is the final pressure? (b) How much work is done by the gas? (c) What is the ratio of the final temperature of the gas to its initial temperature? Is the gas heated or cooled by this compression?

7.5.4. An aircraft engine takes in 9000 J of heat and discards 6400 J each cycle. (a) What is the mechanical work output of the engine during one cycle? (b) What is the thermal efficiency of the engine?

7.5.5. A sophomore with nothing better to do adds heat to 0.350 kg of ice at 0.0°C until it is all melted. Latent heat of ice melting is $3.34 \cdot 10^5$ J/kg. (a) What is the change in entropy of the water? (b) The source of heat is a very massive body at a temperature of 25.0°C. What is the change in entropy of this body? (c) What is the total change in entropy of the water and the heat source?

ANSWERS

Chapter 1

1.1.1. a) $\vec{\boldsymbol{v}} = -12\vec{\boldsymbol{j}}\,\mathrm{m/s^2}\,t$, $\vec{\boldsymbol{a}} = -12\vec{\boldsymbol{j}}\,\mathrm{m/s^2}$ b) $\vec{\boldsymbol{r}} = (3\vec{\boldsymbol{i}} - 6\vec{\boldsymbol{j}})$ m, $\vec{\boldsymbol{v}} = -12\vec{\boldsymbol{j}}$ m/s

1.1.2. a) $\vec{\boldsymbol{v}}_{av}\Big|_0^{2s} = 5\vec{\boldsymbol{i}} + 5\vec{\boldsymbol{j}}$, $v_{av} = 5\sqrt{2}$ m/s b) $\vec{\boldsymbol{v}} = 5t\vec{\boldsymbol{i}} + 5\vec{\boldsymbol{j}}$, $v = 5\sqrt{t^2+1}$ c) $x = 4 + 0.1y^2$

1.1.3. a) $\vec{\boldsymbol{v}} = (v_{0x} + \frac{\alpha t^3}{3})\vec{\boldsymbol{i}} + (v_{0y} + \beta t - \frac{1}{2}\gamma t^2)\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{r}} = (v_{0x}t + \frac{\alpha t^4}{12})\vec{\boldsymbol{i}} + (v_{0y}t + \frac{\beta t^2}{2} - \frac{\gamma t^3}{6})\vec{\boldsymbol{j}}$ b) 341 m c) 176 m

1.1.4. a) 0.6 m/s^2 b) 0.8 m/s^2 c) 1 m/s^2, $\vec{\boldsymbol{a}} = 0.6\vec{\boldsymbol{\tau}} + 0.8\vec{\boldsymbol{n}}$

1.1.5. a) 6.0 s b) $t_1 = -3.0$ s, $x_1 = y_1 = 18$ m; $t_2 = 8$ s, $x_2 = y_2 = 4$ m

1.2.1. a) $\sqrt{2gH}$ b) $g\frac{H}{h}$

1.2.2. $\frac{2b}{3c}$

1.2.3. a) $A = 0$, $B = 2$ m/s^2, $C = 50$ m, $D = 0.5$ m/s^3 b) $\vec{\boldsymbol{v}} = 0$, $\vec{\boldsymbol{a}} = 4\vec{\boldsymbol{i}}$ m/s^2
c) $v_x = 40$ m/s, $v_y = 150$ m/s, $v = 155$ m/s d) $\vec{\boldsymbol{r}} = (200\vec{\boldsymbol{i}} + 550\vec{\boldsymbol{j}})$ m

1.2.4. b) 12.5 m/s^2 c) 5 m/s, $\vec{\boldsymbol{v}} = (4\vec{\boldsymbol{i}} + 3\vec{\boldsymbol{j}})$ m/s

1.2.5. a) 1.225 s b) 1.333 s c) $y = -4 + \frac{3}{2}\sqrt{x+6}$

1.3.1. a) A b) 0 s, 2.28 s, 73 s? c) 1 s, 4.33 s d) 2.67 s

1.3.2. b) $-\frac{26}{3}$ m/s^2, $-\frac{7}{3}$ m/s^2 c) 8.98 m/s^2, 15° below $-x$-axis

1.3.3. a) $\vec{\boldsymbol{r}} = (\alpha t - \frac{\beta}{3}t^3)\vec{\boldsymbol{i}} + \frac{\gamma}{2}t^2\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{a}} = -2\beta t\vec{\boldsymbol{i}} + \gamma\vec{\boldsymbol{j}}$ b) $\frac{3\alpha\gamma}{2\beta} = 9$ m

1.3.4. a) $\vec{\boldsymbol{r}}(t) = (1.5t - 0.5t^2)\vec{\boldsymbol{i}} + (6 - 3t + 1.5t^2)\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{v}}(t) = (1.5 - t)\vec{\boldsymbol{i}} + (-3 + 3t)\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{a}}(t) = -\vec{\boldsymbol{i}} + 3\vec{\boldsymbol{j}}$ b) 1.125 s

1.3.5. $3.7\vec{\boldsymbol{j}} - 2.4t\vec{\boldsymbol{k}}$

1.4.1. a) $(2\vec{\boldsymbol{i}} + 3\vec{\boldsymbol{j}})$ m/s^2 b) $x = 3t + t^2$, $y = 2t + 1.5t^2$

1.4.2. a) $\vec{\boldsymbol{r}} = 5t\vec{\boldsymbol{i}} + 1.5t^2\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{v}} = 5\vec{\boldsymbol{i}} + 3t\vec{\boldsymbol{j}}$ b) $x = 10$ m, $y = 6$ m, $\vec{\boldsymbol{v}} = 7.81$ m/s

1.4.3. b) $\vec{\boldsymbol{v}} = \alpha\vec{\boldsymbol{i}} - 2\beta t\vec{\boldsymbol{j}}$, $\vec{\boldsymbol{a}} = -2\beta\vec{\boldsymbol{j}}$ c) 5.37 m/s, 63° below $+x$-axis, 2.4 m/s^2, along $-y$-axis

1.4.4. $v_x(t) = -A\omega\sin\omega t$, $v_y(t) = A\omega\cos\omega t$, $a_x(t) = -A\omega^2\cos\omega t$, $a_y(t) = -A\omega^2\sin\omega t$

1.4.5. $2.64 \cdot 10^{-4}\ g$

1.5.1. a) s^{-1} b) 0 c) $-u$ d) $-Bu$, 0

1.5.2. a) 3.4 s b) 23.8 m c) ±10 m/s

1.5.3. a) $\vec{\boldsymbol{a}} = -\omega^2 R[\vec{\boldsymbol{i}}\cos(\omega t) + \vec{\boldsymbol{j}}\sin(\omega t)]$ b) $a_n = \omega^2 R$, $a_\tau = 0$
1.5.4. $\vec{\boldsymbol{v}} = 8.0$ m/s $(-\vec{\boldsymbol{i}} + \vec{\boldsymbol{j}})$
1.5.5. a) 843 km/h b) 3500 km S and 1720 km W from initial position c) 780 km/h, 26° W of S

Chapter 2

2.1.1. a) $-(1.92\vec{\boldsymbol{i}} + 10.8\vec{\boldsymbol{j}})$ kg·m/s b) $-(4.95\vec{\boldsymbol{i}} + 6.75\vec{\boldsymbol{j}})$ kg·m/s
2.1.2. a) $W\sin\alpha$ b) $2W\sin\alpha$ c) $W\cos\alpha$
2.1.3. 0 m/s
2.1.4. a) 230 m b) 250 N
2.1.5. 3.1 N
2.2.1. a) $2.5\cdot10^{14}$ m/s^2 b) $1.2\cdot10^{-8}$ s c) $2.28\cdot10^{-16}$ N
2.2.2. a) 12° b) 1.5 m/s
2.2.3. a) 0.556 b) 3 m/s^2, downward
2.2.4. $(1.25\vec{\boldsymbol{i}} - 2.00\vec{\boldsymbol{j}} - 0.30\vec{\boldsymbol{k}})$ m/s
2.2.5. 20 cm from the midpoint of the iron block along the handle
2.3.1. a) 360 N b) 720 N
2.3.2. b) 2.5 m/s^2 c) 1.37 kg d) $T = 0.745$ W
2.3.3. a) 19.3° b) 0.93 m/s^2 c) 3.05 m/s
2.3.4. a) $2\cdot10^{30}$ kg b) 30 km/s
2.3.5. a) 0.4 kg/s b) 5 ms
2.4.1. $(2.0\vec{\boldsymbol{i}} + 1.0\vec{\boldsymbol{j}})$ m/s
2.4.2. 5.0 m
2.4.3. 1.15°
2.4.4. a) 40 m/s= 144 km/h b) 3500 N
2.4.5. 2.87 m/s^2
2.5.1. a) 0.5 N b) 1.2 N
2.5.2. $3.9\cdot10^5$ km
2.5.3. $C = \frac{mv}{R}$
2.5.4. a) $X = Y = 0.6$ m b) $X = Y = 0.5$ m
2.5.5. 1%

Chapter 3

3.1.1. a) $\alpha_z(t) = -1.6\,(\text{rad/s}^3)t$ b) $\alpha_z\big|_{t=3\,s} = -4.8$ rad/s^2; $\alpha_{av-z}\big|_0^{3\,s} = -2.4$ rad/s^2
3.1.2. a) $8.0\cdot10^{-3}$ kg·m^2 b) $4.0\cdot10^{-3}$ kg·m^2 c) $4.0\cdot10^{-3}$ kg·m^2
3.1.3. $1.257\cdot10^3$ kg·m^2/s
3.1.4. c) $(-3.1$ N·m$)\vec{\boldsymbol{k}}$
3.1.5. 785 N·m
3.2.1. a) $a = \pi/4$, $b = 2$ rad/s, $c = 0.2$ rad/s^3 b) zero c) 12.18 rad, 7.4 rad/s
3.2.2. a) $mL^2/2$ b) $11mL^2/16$
3.2.3. $2.26\cdot10^{-2}$ kg·m^2/s
3.2.4. $(17\vec{\boldsymbol{i}} - 19\vec{\boldsymbol{j}} + 14\vec{\boldsymbol{k}})$ N·m
3.2.5. 32 rad/s^2, 8 m/s^2
3.3.1. a) 528 rad b) 12 s c) -8.4 rad/s^2
3.3.2. $\frac{7}{5}MR^2$
3.3.3. a) $2.7\cdot10^{40}$ kg·m^2/s b) $7.15\cdot10^{32}$ kg·m^2/s
3.3.4. 18.85 N
3.3.5. 503 N·m, 600 rev

3.4.1. 19.5 rad/s
3.4.2. $2.5 \cdot 10^{-3}$ kg·m^2
3.4.3. 0.6 rev
3.4.4. 10.05 N
3.4.5. a) 0.63 N·m b) 135 rev
3.5.1. a) 1.207 s b) 8.624 rad/s^2
3.5.2. a) 0.25 m/s^2 b) 1.00 N c) 0.1 kg
3.5.3. $\approx 1.0 \cdot 10^{-3}$ s
3.5.4. a) 0.50 N·m b) 8 Hz
3.5.5. $4.2 \cdot 10^{-2}$ kg·m^2

Chapter 4

4.1.1. a) $8.00 \cdot 10^5$ J, $6.93 \cdot 10^5$ J b) $-8.00{\cdot}10^5$ J, $-6.93{\cdot}10^5$ J c) 0 J
4.1.2. a) $4\,d$ b) $\frac{d}{2}$
4.1.3. a) 7.92 m/s b) 8.87 m/s c) 8.87 m/s
4.1.4. a) $F_x = 3x^2 - 8x - 3$ b) $x_1 = -1/3$ m, $x_2 = 3$ m c) x_1 – stable, x_2 – unstable
4.1.5. 50 MW
4.2.1. -49 J
4.2.2. 8 cm
4.2.3. 7.8 m/s
4.2.4. $\frac{\alpha}{r^3}\left(x\vec{\boldsymbol{i}} + y\vec{\boldsymbol{j}} + z\vec{\boldsymbol{k}}\right)$
4.2.5. 2.5 m
4.3.1. a) $42.85\,v_p$ b) $K_e/1836$ c) $1836\,K_e$
4.3.2. a) 0.16 J b) 0.4 m/s
4.3.3. a) 2 J b) -18 J c) -20 J
4.3.4. a) 597 N·m b) $3.75 \cdot 10^3$ J
4.3.5. 4.0 m/s
4.4.1. a) 25 m/s b) 31.25 m
4.4.2. -30 W
4.4.3. 11 km/s
4.4.4. a) $ax^2 + bx^4$ b) $3a + 15b$ c) $-3a - 15b$
4.4.5. 6 m/s
4.5.1. 250 J
4.5.2. a) 2 m/s b) 4.75 cm after release c) 2.12 m/s
4.5.3. 300 m
4.5.4. a) 6.60 kW b) 12.0 kW
4.5.5. 12.4 km/s

Chapter 5

5.1.1. 80 kg
5.1.2. a) 1.04 J b) 0.102 m c) 2.55 m/s
5.1.3. 1.2 rad/s
5.1.4. 1.6 Hz
5.1.5. a) 4.0 m b) 4.0 m c) 100 Hz d) 400 m/s
5.2.1. a) 5.6 Hz b)7.2 Hz
5.2.2. 0.2 m
5.2.3. 0.1 kg/s
5.2.4. $\sqrt{\omega_0^2 - 2\beta^2}$
5.2.5. a) 20 m/s b) 0.045 m c) both decrease by factor of 2
5.3.1. a) 1.047 s b) 108 N/m c) 0.48 m/s d) 8.64 N e) 0.0 m; 0.48 m/s; 2.88 m/s^2 f) 8.64 N
5.3.2. a) 1.25 m/s b) 1 m/s c) 31.25 m/s^2 d) 18.25 m/s^2

e) 3.125 J

5.3.3. 6.314 s

5.3.4. a) 5 rad/s b) 3 rad/s c) 0.25 m

5.3.5. 222 m/s = 800 km/h

5.4.1. a) 0.4 m b) $-\pi/2$ rad c) $x(t) = (0.4\text{ m})\sin([20\text{ rad/s}]t)$

5.4.2. a) $\frac{\sqrt{2}}{2}A$, $\frac{\sqrt{2}}{2}A\omega$ b) 4 times per cycle, $\frac{\pi}{2\omega}$ c) 3/4, 1/4

5.4.3. a) 3.14 rad/s b) 0.02 s^{-1} c) −9.4 cm d) −10.6 cm

5.4.4. 9.0 N

5.4.5. a) 0.13 W b) increased by factor of 4

5.5.1. a) 100 N/m b) 0.4 m

5.5.2. a) $-\frac{2T}{L}y$ b) $\sqrt{\frac{2T}{mL}}$

5.5.3. a) 7.96 Hz b) 1.26 % c) 11.5 s

5.5.4. a) 2.0 s^{-1} b) 2.0 kg/s

5.5.5. a) 0.392 m, 1.136 ms b) 0.784 m

Chapter 6

6.1.1. a) 983°C b) 0.52 g

6.1.2. a) 36.5 kN b) 46.5 kN

6.1.3. a) 1.028 b) ^{35}Cl

6.1.4. a) 3.5 nm

6.1.5. 0.368

6.2.1. 1.0 atm

6.2.2. a) 300 K b) (i) 300 K, $5 \cdot 10^4$ Pa (ii) 600 K, 10^5 Pa

6.2.3. a) $2.2 \cdot 10^6$ b) $2.4 \cdot 10^{19}$

6.2.4. a) 731 m/s b) 825 m/s c) 895 m/s

6.2.5. a) the same b) $v_{\text{rms}}^{\text{Ne}} > v_{\text{rms}}^{\text{Kr}} > v_{\text{rms}}^{\text{Rn}}$

6.3.1. a) $8.75 \cdot 10^{-21}$ J b) $v_{\text{rms}}^{\text{He}} = 1.62$ km/s, $v_{\text{rms}}^{\text{Ar}} = 513$ m/s

6.3.2. 1.05 atm

6.3.3. a) $3.54 \cdot 10^{23}$ b) $6.065 \cdot 10^{-21}$ J c) 1.35 km/s

6.3.4. $6.38 \cdot 10^{-6}$ m

6.3.5. 4527°C

6.4.1. $5.0 \cdot 10^{-21}$ J

6.4.2. a) 3.74

6.4.3. 501 K

6.4.4. 55.6 mol, $3.35 \cdot 10^{25}$ molecules

6.4.5. a) 6.4 mm/s b) No

6.5.1. $3.1 \cdot 10^{-10}$ m

6.5.2. a) $6.1 \cdot 10^4$ Pa, 308 K b) $3.5 \cdot 10^{-3}$ m^3 c) 0.77 atm

6.5.3. $22.4 \cdot 10^{-3}$ m^3, 1.29 kg/m^3

6.5.4. a) 742 K b) 6.2 MPa

6.5.5. 128 m/s

Chapter 7

7.1.1. a) 1558 J b) 935 J

7.1.2. a) 321 K, 451 K b) 3.25 kJ c) 8.1 kJ d) 4.85 kJ

7.1.3. b) 25.1 atm, 768 K

7.1.4. a) 643 kJ/s b) 463 kJ/s

7.1.5. a) 31°C b) 10 J/K

7.2.1. 4.15 K

7.2.2. a) -605 J b) 0 c) 605 J, liberate
7.2.3. b) 224 J c) -224 J
7.2.4. a) 215 J b) 378 K c) 39%
7.2.5. 20 J/K
7.3.1. a) 1385 J/(kg·K)
7.3.2. a) $1.15 \cdot 10^5$ J
b) $1.29 \cdot 10^5$ J, out
7.3.3. $C_V = 65.43$ J/(K·mol),
$C_P = 73.74$ J/(K·mol)
7.3.4. a) $4.24 \cdot 10^4$ J b) 715 K
7.3.5. 8 J/K
7.4.1. 62.1 K
7.4.2. a) 1, 3 b) 1, absorbed
7.4.3. a) 747 J b) 1.3
7.4.4. a) 4500 J b) 320 K
7.4.5. b) $W_{P=\text{const}} = P_1V_1$,
$W_{T=\text{const}} = P_1V_1 \ln 2$
c) $\Delta S_{P=\text{const}} = \nu C_P \ln 2$,
$\Delta S_{T=\text{const}} = \nu R \ln 2$
7.5.1. b) -6540 J
7.5.2. 240 J
7.5.3. a) $4.76 \cdot 10^5$ Pa
b) -10.6 kJ c) 1.59
7.5.4. a) 2600 J b) 28.9%
7.5.5. a) 428 J/K b) -392 J/K
c) 36 J/K

APPENDIX

Universal physical constants

$G = 6.674 \cdot 10^{-11}$ N·m^2/kg^2	Gravitational constant	Universal law of gravity
$c = 299\,792\,458$ m/s	Speed of light in vacuum	$c \approx 3 \cdot 10^8$ m/s
$k_B = 1.38 \cdot 10^{-23}$ J/K	Boltzmann's constant	Entropy of a thermodynamic system
$N_A = 6.02 \cdot 10^{23}$ mol^{-1}	Avogadro's number	Number of molecules in 1 mole of substance
$R = 8.31$ J/(K·mol)	Universal gas constant	$R = k_B N_A$

Some properties of the Earth

$L_E = 4.0 \cdot 10^7$ m	Length of the Earth meridian	Former definition of one meter
$R_E = L_E/(2\pi)$	Average radius of the Earth	$R_E \approx 6.4 \cdot 10^6$ m
$R_O = 1.5 \cdot 10^{11}$ m	Average radius of the orbit of the Earth	
$T_O = 3.15576 \cdot 10^7$ s	Period of orbital motion of the Earth, one solar year	$T_O \approx 365.25$ day $\cdot$ 24 h $\cdot$ 60 min $\cdot$ 60 s, former definition of one second
$M_E = 6.0 \cdot 10^{24}$ kg	Mass of the Earth	$M_E = gR_E^2/G$
$g = 9.81$ м/с^2	Acceleration due to gravity	$g \approx 10$ m/s^2 (in calculations)
$\mu_{\text{air}} = 29 \cdot 10^{-3}$ kg/mol	Molar mass of the air	
$\gamma_{\text{air}} = 1.4$	Adiabatic constant of the air	N_2:$O_2 \approx 80 : 20$ – air composition
$T_{\text{st}} = 0$ °C	Standard conditions	$T_{\text{st}} \approx 273$ K
$P_{\text{st}} = 1$ atm $= 1.013 \cdot 10^5$ Pa	Standard conditions	$P_{\text{st}} \approx 10^5$ Pa

Derivatives. Basic rules

$$\frac{d(f+g)}{dx} = \frac{df}{dx} + \frac{dg}{dx} \qquad \frac{d(Cf)}{dx} = C\frac{df}{dx} \quad (C = \text{const})$$

$$\frac{d(f\,g)}{dx} = \frac{df}{dx}\,g + f\,\frac{dg}{dx} \qquad \frac{d\left(\frac{f}{g}\right)}{dx} = \frac{\frac{df}{dx}\,g - f\,\frac{dg}{dx}}{g^2}$$

$$\frac{d}{dx}\,[f(g(x))] = \frac{df}{dg}\,\frac{dg}{dx} \qquad \frac{dx}{dy} = \left(\frac{dy}{dx}\right)^{-1} \quad \left(\frac{dy}{dx} \neq 0\right)$$

Derivatives of some functions

$$\frac{dC}{dx} = 0 \qquad \frac{dx}{dx} = 1$$

$$\frac{d}{dx}\,(x^\alpha) = \alpha x^{\alpha-1} \qquad \frac{d}{dx}\,(\exp^x) = \exp^x$$

$$\frac{d}{dx}\,(\sin x) = \cos x \qquad \frac{d}{dx}\,(\cos x) = -\sin x$$

$$\frac{d}{dx}\,(\ln x) = \frac{1}{x} \qquad \frac{d}{dx}\,(\tan x) = \frac{1}{\cos^2 x}$$

Fundamental Theorem of Calculus

$$\int\limits_a^b f(x)\,dx = F(b) - F(a), \text{ where } F(x) - \text{ an antiderivative of } f(x)$$

$$F(x) - \text{ is an antiderivative of } f(x) \Leftrightarrow \frac{dF(x)}{dx} = f(x)$$

Antiderivatives of some functions [1]

$$\int dx = x \qquad \int x^\alpha\,dx = \frac{x^{\alpha+1}}{\alpha+1} \quad (\alpha \neq -1)$$

$$\int \frac{dx}{x} = \ln|x| \qquad \int \exp^x\,dx = \exp^x$$

$$\int \sin x\,dx = -\cos x \qquad \int \cos x\,dx = \sin x$$

$$\int \frac{dx}{1+x^2} = \arctan x \qquad \int \frac{dx}{1-x^2} = \ln\left|\frac{1-x}{1+x}\right|$$

[1] An arbitrary constant can be added to the right part of every equations.

Dot (scalar) product of vectors

$$\vec{a}\cdot\vec{b}\overset{def}{=}|\vec{a}||\vec{b}|\cos\left(\angle\vec{a}\vec{b}\right)=\vec{b}\cdot\vec{a}$$

$$\vec{i}\cdot\vec{i}=\vec{j}\cdot\vec{j}=\vec{k}\cdot\vec{k}=1$$

$$\vec{i}\cdot\vec{j}=\vec{j}\cdot\vec{k}=\vec{k}\cdot\vec{i}=0$$

$$\vec{a}=a_x\vec{i}+a_y\vec{j}+a_z\vec{k},$$

$$\vec{b}=b_x\vec{i}+b_y\vec{j}+b_z\vec{k}$$

$$\vec{a}\cdot\vec{b}=a_xb_x+a_yb_y+a_zb_z$$

Cross (vector) product of vectors

$$|\vec{a}\times\vec{b}|\overset{def}{=}|\vec{a}||\vec{b}|\sin\left(\angle\vec{a}\vec{b}\right)$$

$$\vec{i}\times\vec{i}=\vec{j}\times\vec{j}=\vec{k}\times\vec{k}=0$$

$$\vec{a}\perp\left(\vec{a}\times\vec{b}\right)\perp\vec{b}$$

$$\vec{a}\times\vec{b}=-\vec{b}\times\vec{a}$$

$$\vec{i}\times\vec{j}=\vec{k},\quad \vec{j}\times\vec{k}=\vec{i},\quad \vec{k}\times\vec{i}=\vec{j}$$

$$\vec{a}=a_x\vec{i}+a_y\vec{j}+a_z\vec{k},$$

$$\vec{b}=b_x\vec{i}+b_y\vec{j}+b_z\vec{k}$$

$$\vec{a}\times\vec{b}=\vec{i}(a_yb_z-a_zb_y)+\vec{j}(a_zb_x-a_xb_z)+\vec{k}(a_xb_y-a_yb_x)$$

$$\vec{a}\times\vec{b}=\begin{vmatrix}\vec{i} & \vec{j} & \vec{k}\\ a_x & a_y & a_z\\ b_x & b_y & b_z\end{vmatrix}$$

Scalar triple product

$$\vec{a}\cdot\left(\vec{b}\times\vec{c}\right)=\vec{b}\cdot(\vec{c}\times\vec{a})=\vec{c}\cdot\left(\vec{a}\times\vec{b}\right)=-\vec{c}\cdot\left(\vec{b}\times\vec{a}\right)$$

Vector triple product

$$\vec{a}\times\left(\vec{b}\times\vec{c}\right)=\vec{b}\left(\vec{a}\cdot\vec{c}\right)-\vec{c}\left(\vec{a}\cdot\vec{b}\right)$$

Bibliography

1. Sears and Zemansky's University Physics: with Modern Physics. — 12th ed./Hugh D. Young, Roger A. Freedman; contributing author, A. Lewis Ford. — Pearson Education, Inc., publishing as Pearson Addison-Wesley. — 2008. — 1632 pg.
2. Physics for Scientists and Engineers with Modern Physics. — Third ed./Paul M. Fishbane, Stephen G. Gasiorowicz, Stephen T. Thornton . — Pearson Prentice Hall Pearson Education. Inc. — 2005. — 1379 pg.
3. Physics for Scientists and Engineers with Modern Physics. — 8th ed./ Raymond A. Serway, John W. Jewett — Brooks/Cole Cengage Leaning. — 2010. — 1558 pg.
4. Савельев, И.В. Курс общей физики : в 3 т. [Текст] / И.В. Савельев. — СПб. : Лань, 2008.
5. Джанколи, Д. Физика : в 2 т. [Текст] / Д. Джанколи. — М. : Мир, 1989.
6. Сивухин, Д.В. Общий курс физики : в 5 т. [Текст] / Д.В.Сивухин. — М. : Наука, 1989.
7. Механіка. Молекулярна фізика. Термодинаміка [Текст] : навч. посіб. до практ. занять з фізики /А. М. Охрімовський, П. А. Комозинський, О. В. Подшивалова, О. М. Чугай. — Х. : Нац. аерокосм. ун-т "Харк. авіац. ін-т", 2010. – 108 с.

Навчальне видання

Охрімовський Андрій Михайлович
Подшивалова Оксана Володимирівна

МЕХАНІКА І ТЕРМОДИНАМІКА

(Англійською мовою)

Редактор Є. В. Пизіна
Технічний редактор Л. О. Кузьменко

Зв. план, 2012
Підписано до друку 27.04.2012
Формат 60x84 1/16. Папір офс. № 2. Офс. друк
Ум. друк. арк. 4. Обл.-вид. арк. 4,5. Наклад 300 пр.
Замовлення 167. Ціна вільна

Національний аерокосмічний університет ім. М. Є. Жуковського
"Харківський авіаційний інститут"
61070, Харків-70, вул. Чкалова, 17
http://www.khai.edu
Видавничий центр "ХАІ"
61070, Харків-70, вул. Чкалова, 17
izdat@khai.edu

Свідоцтво про внесення суб'єкта видавничої справи
до Державного реєстру видавців, виготовлювачів і розповсюджувачів
видавничої продукції сер. ДК № 391 від 30.03.2001