ALNOJOUM ACADEMY

أكاديمية النجوم

Chapter 5
Force and Motion — I

Written solutions to the textbook problems

PHYS 105 | Prince Sultan University | 12 solved problems

What this chapter covers

5.1 Newton's First and Second Laws

5.2 Some Particular Forces

5.3 Applying Newton's Laws

All key formulas are on the next page.

Watch out

- Free-body diagram: draw only the forces acting **on** the body (W, N, T, f, applied F) — never ma or v; N is perpendicular to the surface.
- Draw a free-body diagram first and choose a positive direction.
- ΣF = ma uses the **net** force — add all forces with their signs.
- If an object moves down and slows down, its acceleration points **up**.
- Constant speed (even on an incline) means a = 0, so ΣF = 0.
- Convert mi/h and km/h to m/s, and ms to s, before using F = ma.

Problems in this file

1 A rock on a far-away planet

2 Pushing a shopping cart

3 Pulling a sister on a sled

4 Average force on a billiard ball

5 A water skier pulled from rest

6 A parachutist landing

7 A baseball pitch

8 Stopping a 747

9 A drag racer's chute

10 A catcher stopping a pitch

11 Braking for a ball in the street

12 Towing a trailer up an incline

Every problem has a QR code that opens its full video solution.

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Chapter 5

Key formulas

Organized by the sections of the Chapter 5 slides (5.1 – 5.3).

5.1 Newton's First and Second Laws

First law	$\Sigma\vec{F} = 0 \Leftrightarrow \vec{v} = \text{constant}$	Inertia; at rest or constant velocity
Second law	$\Sigma\vec{F} = m\vec{a}$	$\Sigma F_x = m a_x$, $\Sigma F_y = m a_y$
Unit of force	$1\ \text{N} = 1\ \text{kg·m/s}^2$	

5.2 Some Particular Forces

Weight	$W = mg$	Directed down; g = 9.81 m/s²
Normal force (flat, no other vertical force)	$N = mg$	Perpendicular to the surface
Normal force on an incline	$N = mg\cos\theta$	Along the incline: mg sin θ
Apparent weight (elevator)	$W_a = m(g + a)$	a > 0 up, a < 0 down
Tension	T	Pulls along the rope; same throughout an ideal rope

5.3 Applying Newton's Laws

Third law	$\vec{F}_{AB} = -\vec{F}_{BA}$	Equal and opposite, on different bodies
Frictionless incline	$a = g\sin\theta$	
Two blocks pushed together	$a = \dfrac{F}{m_1 + m_2}, \quad F_{contact} = m_2 a$	
Atwood machine	$a = \dfrac{(m_1 - m_2)g}{m_1 + m_2}$	$T = m_2(g + a)$

◆ Apparent weight in an elevator

	ACCELERATION	SCALE READING
At rest / constant velocity	0	N = mg
Accelerating up	+a	N = m(g + a) > mg
Accelerating down	−a	N = m(g − a) < mg
Free fall	−g	N = 0 (weightless)

PROBLEM 1

A rock on a far-away planet

Second law · Net force

Watch the video

On a planet far, far away, an astronaut picks up a rock. The rock has a mass of 5.00 kg, and on this planet its weight is 40.0 N. If the astronaut exerts an upward force of 46.2 N on the rock, what is its acceleration?

GIVEN $m = 5.00\ \text{kg}$ $W = 40.0\ \text{N}$ $F = 46.2\ \text{N (up)}$ **FIND** a

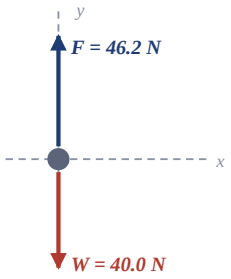
SOLUTION

Net force (up is +):

$$\Sigma F_y = 46.2 - 40.0 = 6.2\ \text{N}$$

$$a = \frac{\Sigma F_y}{m} = \frac{6.2}{5.00} = 1.24\ \text{m/s}^2\ \text{(upward)}$$

FREE-BODY DIAGRAM



ANSWER $1.24\ \text{m/s}^2$ up

PROBLEM 2

Pushing a shopping cart

Second law · Kinematics

Watch the video

In a grocery store, you push a 12.3-kg shopping cart with a force of 10.1 N. If the cart starts at rest, how far does it move in 2.50 s?

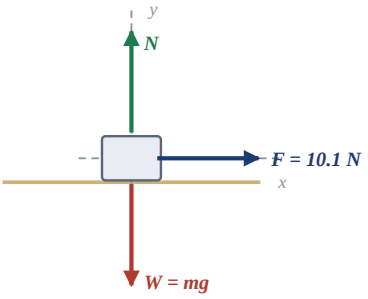
GIVEN $m = 12.3\ \text{kg}$ $F = 10.1\ \text{N}$ $v_0 = 0$ $t = 2.50\ \text{s}$ **FIND** Δx

SOLUTION

$$a = \frac{F}{m} = \frac{10.1}{12.3} = 0.821\ \text{m/s}^2$$

$$\Delta x = \tfrac{1}{2}at^2 = \tfrac{1}{2}(0.821)(2.50)^2 = 2.57\ \text{m}$$

FREE-BODY DIAGRAM



ANSWER $2.57\ \text{m}$

PROBLEM 3

Pulling a sister on a sled

Second law · System mass

Watch the video

You are pulling your little sister on her sled across an icy (frictionless) surface. When you exert a constant horizontal force of 120 N, the sled has an acceleration of 2.5 m/s². If the sled has a mass of 7.4 kg, what is the mass of your little sister?

GIVEN $F = 120\ \text{N}$ $a = 2.5\ \text{m/s}^2$ $m_{sled} = 7.4\ \text{kg}$ FIND m_{girl}

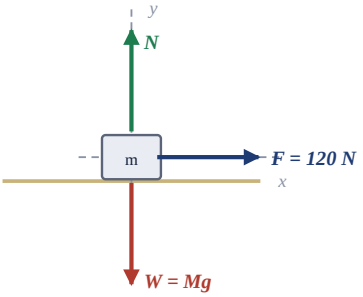
SOLUTION

Total mass being accelerated:

$$M = \frac{F}{a} = \frac{120}{2.5} = 48\ \text{kg}$$

$$m_{girl} = 48 - 7.4 = 40.6\ \text{kg}$$

FREE-BODY DIAGRAM



M = sled + sister

ANSWER $40.6\ \text{kg}$

PROBLEM 4

Average force on a billiard ball

Second law · Average force

Watch the video

A 0.53-kg billiard ball initially at rest is given a speed of 12 m/s during a time interval of 4.0 ms. What average force acted on the ball during this time?

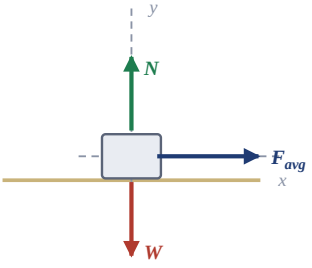
GIVEN $m = 0.53\ \text{kg}$ $v_0 = 0$ $v = 12\ \text{m/s}$ $\Delta t = 4.0 \times 10^{-3}\ \text{s}$ FIND F_{avg}

SOLUTION

$$a = \frac{12 - 0}{4.0 \times 10^{-3}} = 3.0 \times 10^{3}\ \text{m/s}^2$$

$$F = ma = 0.53(3.0 \times 10^{3}) = 1.6 \times 10^{3}\ \text{N}$$

FREE-BODY DIAGRAM



N and W cancel (vertical)

ANSWER $1.6 \times 10^{3}\ \text{N}$

PROBLEM 5

A water skier pulled from rest

Second law · Kinematics

Watch the video

A 92-kg water skier floating in a lake is pulled from rest to a speed of 12 m/s in a distance of 25 m. What is the net force exerted on the skier, assuming his acceleration is constant?

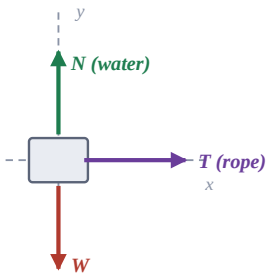
GIVEN $m = 92\ \text{kg}$ $v_0 = 0$ $v = 12\ \text{m/s}$ $\Delta x = 25\ \text{m}$ **FIND** ΣF

SOLUTION

$$a = \frac{v^2}{2\Delta x} = \frac{12^2}{2(25)} = 2.88\ \text{m/s}^2$$

$$\Sigma F = ma = 92(2.88) = 265\ \text{N}$$

FREE-BODY DIAGRAM



N and W cancel; ΣF = T

ANSWER $265\ \text{N}$

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PROBLEM 6

A parachutist landing

Second law · Normal force

Watch the video

A 42.0-kg parachutist is moving straight downward with a speed of 3.85 m/s. (a) If the parachutist comes to rest with constant acceleration over a distance of 0.750 m, what force does the ground exert on her? (b) If she comes to rest over a shorter distance, is the force exerted by the ground greater than, less than, or the same as in part (a)? Explain.

GIVEN $m = 42.0\ \text{kg}$ $v_0 = 3.85\ \text{m/s (down)}$ $v = 0$ $d = 0.750\ \text{m}$ **FIND** N

SOLUTION

She moves down and slows down, so her acceleration points **up**:

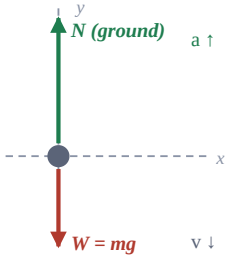
$$a = \frac{v_0^2}{2d} = \frac{3.85^2}{2(0.750)} = 9.88\ \text{m/s}^2\ \text{(up)}$$

(a) Second law with up positive — the ground force N must also hold up her weight:

$$N - mg = ma \rightarrow N = m(g + a) = 42.0(9.81 + 9.88) = 827\ \text{N}$$

Note: the *net* force is ma = 415 N upward; the ground force is larger because it also cancels the weight.

FREE-BODY DIAGRAM



(b) A shorter stopping distance needs a larger $a = v_0^2/2d$, so $N = m(g + a)$ is **greater**.

ANSWER **(a)** 827 N (up) **(b)** greater

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PROBLEM 7

A baseball pitch

Second law · Unit conversion

Watch the video

In baseball, a pitcher can accelerate a 0.15-kg ball from rest to 98 mi/h in a distance of 1.7 m. (a) What is the average force exerted on the ball during the pitch? (b) If the mass of the ball is increased, is the force required of the pitcher increased, decreased, or unchanged? Explain.

GIVEN $m = 0.15\ \text{kg}$ $v = 98\ \text{mi/h} = 43.8\ \text{m/s}$ $\Delta x = 1.7\ \text{m}$ **FIND** F

SOLUTION

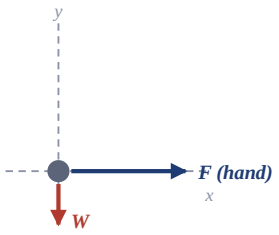
$$a = \frac{v^2}{2\Delta x} = \frac{43.8^2}{2(1.7)} = 564\ \text{m/s}^2$$

(a)

$$F = ma = 0.15(564) = 84.6\ \text{N}$$

(b) Same speed and distance → same a; since F = ma, a larger mass needs a **larger** force.

FREE-BODY DIAGRAM



W ≪ F during the pitch

ANSWER **(a)** 84.6 N **(b)** increased

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PROBLEM 8

Stopping a 747

Second law · Kinematics

Watch the video

A 747 jetliner lands and begins to slow to a stop as it moves along the runway. If its mass is 3.50 × 10^5 kg, its speed is 27.0 m/s, and the net braking force is 4.30 × 10^5 N, (a) what is its speed 7.50 s later? (b) How far has it traveled in this time?

GIVEN $m = 3.50 \times 10^5\ \text{kg}$ $v_0 = 27.0\ \text{m/s}$ $F = 4.30 \times 10^5\ \text{N}$ $t = 7.50\ \text{s}$ **FIND** $v,\ \Delta x$

SOLUTION

The braking force is opposite to the motion:

$$a = -\frac{4.30 \times 10^5}{3.50 \times 10^5} = -1.23\ \text{m/s}^2$$

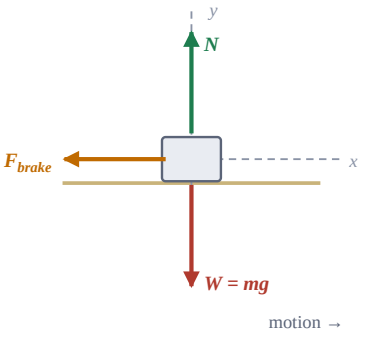
(a)

$$v = 27.0 + (-1.23)(7.50) = 17.8\ \text{m/s}$$

(b)

$$\Delta x = 27.0(7.50) + \tfrac{1}{2}(-1.23)(7.50)^2 = 168\ \text{m}$$

FREE-BODY DIAGRAM



ANSWER **(a)** 17.8 m/s **(b)** 168 m

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PROBLEM 9

A drag racer's chute

Second law · Unit conversion

Watch the video

A drag racer crosses the finish line doing 202 mi/h and promptly deploys her drag chute. (a) What force must the drag chute exert on the 891-kg car to slow it to 45.0 mi/h in a distance of 185 m? (b) Describe the strategy you used to solve part (a).

GIVEN $v_0 = 202\ \text{mi/h} = 90.3\ \text{m/s}$ $v = 45.0\ \text{mi/h} = 20.1\ \text{m/s}$ $\Delta x = 185\ \text{m}$ $m = 891\ \text{kg}$ FIND F

SOLUTION

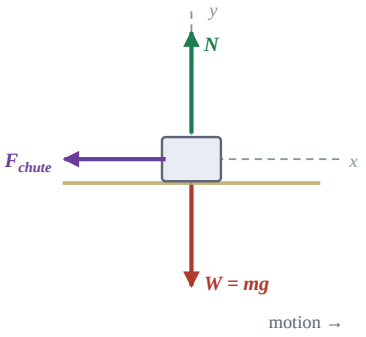
$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{20.1^2 - 90.3^2}{2(185)} = -20.9\ \text{m/s}^2$$

(a)

$$F = m|a| = 891(20.9) = 1.87 \times 10^4\ \text{N}$$

(b) Strategy: convert to m/s → use kinematics ($v^2 = v_0^2 + 2a\Delta x$) to get a → use F = ma.

FREE-BODY DIAGRAM



ANSWER **(a)** $1.87 \times 10^4\ \text{N}$

PROBLEM 10

A catcher stopping a pitch

Second law · Finding mass

Watch the video

A major-league catcher gloves a 92-mi/h pitch and brings it to rest in 0.15 m. If the force exerted by the catcher is 803 N, what is the mass of the ball?

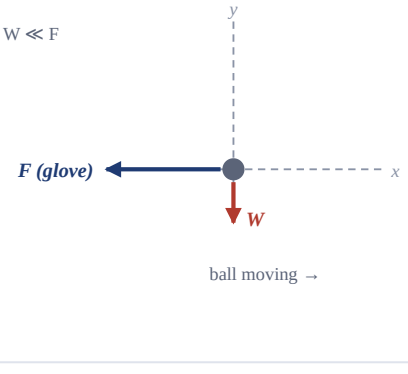
GIVEN $v_0 = 92\ \text{mi/h} = 41.1\ \text{m/s}$ $v = 0$ $\Delta x = 0.15\ \text{m}$ $F = 803\ \text{N}$ FIND m

SOLUTION

$$|a| = \frac{v_0^2}{2\Delta x} = \frac{41.1^2}{2(0.15)} = 5.64 \times 10^3\ \text{m/s}^2$$

$$m = \frac{F}{a} = \frac{803}{5.64 \times 10^3} = 0.142\ \text{kg} = 142\ \text{g}$$

FREE-BODY DIAGRAM



ANSWER $0.142\ \text{kg}$

PROBLEM 11

Braking for a ball in the street

Second law · Kinematics

Watch the video

Driving home from school one day, you spot a ball rolling out into the street (Figure 5-18). You brake for 1.20 s, slowing your 950-kg car from 16.0 m/s to 9.50 m/s. (a) What was the average force exerted on your car during braking? (b) How far did you travel while braking?

GIVEN $m = 950\ \text{kg}$ $v_0 = 16.0\ \text{m/s}$ $v = 9.50\ \text{m/s}$ $t = 1.20\ \text{s}$ FIND $F,\ \Delta x$

SOLUTION

$$a = \frac{9.50 - 16.0}{1.20} = -5.42\ \text{m/s}^2$$

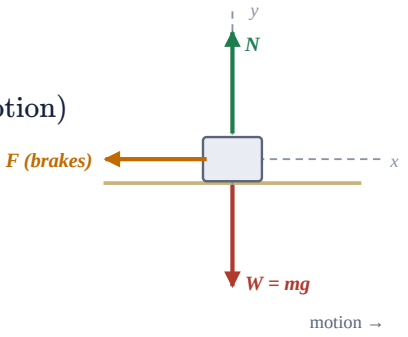
(a)

$$F = ma = 950(-5.42) = -5.15 \times 10^3\ \text{N (opposite to the motion)}$$

(b)

$$\Delta x = \frac{v_0 + v}{2}t = \frac{16.0 + 9.50}{2}(1.20) = 15.3\ \text{m}$$

FREE-BODY DIAGRAM



ANSWER **(a)** $5.15 \times 10^3\ \text{N}$ **(b)** $15.3\ \text{m}$

PROBLEM 12

Towing a trailer up an incline

Equilibrium · Inclined plane

Watch the video

A farm tractor tows a 3700-kg trailer up an 18° incline with a steady speed of 3.2 m/s. What force does the tractor exert on the trailer? (Ignore friction.)

GIVEN $m = 3700\ \text{kg}$ $\theta = 18^\circ$ $v = \text{constant}$ FIND F

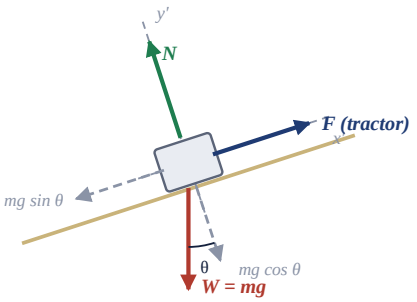
SOLUTION

Steady speed → a = 0 → ΣF = 0 along the incline:

$$F - mg\sin\theta = 0$$

$$F = 3700(9.81)\sin 18^\circ = 1.12 \times 10^4\ \text{N}$$

FREE-BODY DIAGRAM



ANSWER $1.12 \times 10^4\ \text{N}$

Answer summary

Problem	Topic	Key physics idea	Final answer(s)
1	A rock on a far-away planet	**$\Sigma F = ma$ with the weight**	$1.24\ \text{m/s}^2$ up
2	Pushing a shopping cart	**$F \to a \to \Delta x$**	$2.57\ \text{m}$
3	Pulling a sister on a sled	**a is shared by the whole system**	$40.6\ \text{kg}$
4	Average force on a billiard ball	**$F = m\,\Delta v / \Delta t$**	$1.6 \times 10^3\ \text{N}$
5	A water skier pulled from rest	**Kinematics gives a, then $F = ma$**	$265\ \text{N}$
6	A parachutist landing	**Slowing down while falling → a points up**	**(a)** $827\ \text{N}$ (up) **(b)** greater
7	A baseball pitch	**Larger m → larger F**	**(a)** $84.6\ \text{N}$ **(b)** increased
8	Stopping a 747	**Braking force gives $a < 0$**	**(a)** $17.8\ \text{m/s}$ **(b)** $168\ \text{m}$
9	A drag racer's chute	**Convert units first**	**(a)** $1.87 \times 10^4\ \text{N}$
10	A catcher stopping a pitch	**$m = F / a$**	$0.142\ \text{kg}$
11	Braking for a ball in the street	**Average force from $\Delta v / \Delta t$**	**(a)** $5.15 \times 10^3\ \text{N}$ **(b)** $15.3\ \text{m}$
12	Towing a trailer up an incline	**Constant speed → $\Sigma F = 0$**	$1.12 \times 10^4\ \text{N}$

$g = 9.81\ \text{m/s}^2$. $1\ \text{mi} = 1609\ \text{m}$. Answers are rounded to the significant figures given in each problem.

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