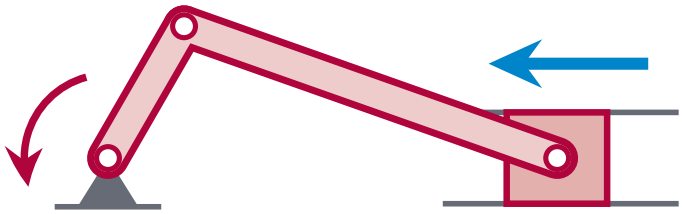
DYNAMICS

WORKBOOK

11 chapters · 160 problems · step-by-step solutions



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How to use this book

- Each chapter opens with a reminder box summarizing the definitions and formulas the problems rely on.
- Difficulty: ★☆☆ basic ★★☆ intermediate ★★★ advanced. Each chapter has a few multiple-choice concept questions; its last problem is an exam-style mixed problem combining several topics.
- The dotted area below each problem is for your own work. Solve first; if stuck, go back to the reminder box and the lecture notes, and look at the solution last.
- All solutions are at the end of the book. The Solution → p. link next to a problem takes you to its solution, and ← Problem p. takes you back. Short answers are in the **ANSWER** box.
- **Midterm and final:** At most universities the midterm covers the dynamics of a particle (Chapters 1–6); in some courses impulse and momentum (Chapter 6) is left to the final. In courses with two midterms, the second covers the kinematics and kinetics of a rigid body (Chapters 7–9). The final usually covers everything, with the emphasis on rigid bodies. Choose the chapters to study according to your own course syllabus.

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Solutions 113

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CHAPTER 1

RECTILINEAR MOTION

definitions	$v = \frac{ds}{dt},\ a = \frac{dv}{dt},\ a\,ds = v\,dv$	$a(t)$	$v = v_0 + \int_0^t a\,dt$
constant a	$v = v_0 + at,\ s = s_0 + v_0 t + \frac{1}{2}at^2$	$a(v)$	$dt = \frac{dv}{a},\ ds = \frac{v\,dv}{a}$
	$v^2 = v_0^2 + 2a(s - s_0)$	$a(s)$	$\frac{1}{2}v^2 - \frac{1}{2}v_0^2 = \int_{s_0}^{s} a\,ds$
		graphs	$\Delta v = a$–t area, $\Delta s = v$–t area

All motions are along a straight line. The positive direction is stated in each solution; upward is positive for vertical motions. Air resistance is neglected, and $g = 9.81$ m/s^2. Velocity is a signed quantity; speed is its magnitude.

Position, velocity, and acceleration

1.1 ★☆☆ Solution → p. 113

Which of the following is *always* true for a particle moving along a straight line?

A) The average speed over a time interval cannot be less than the magnitude of the average velocity over the same interval.

B) When the velocity is zero, the acceleration is also zero.

C) If the acceleration is negative, the particle is slowing down.

D) The total distance traveled equals the magnitude of the difference between the final and initial positions.

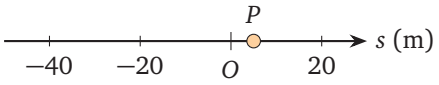
E) Velocity and acceleration are in the same direction at every instant.

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1.2

★☆☆ Solution → p. 113

The position of a particle moving along a straight line is given by



$$s = 2t^3 - 18t^2 + 30t + 5$$

(s in meters, t in seconds).

a. During which time interval does the particle move in the negative direction? What is its greatest speed in this interval?

b. For $0 \leq t \leq 6$ s, find the displacement, the total distance traveled, the average velocity, and the average speed.

c. At $t = 6$ s, is the particle speeding up or slowing down?

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SOLUTIONS

1 RECTILINEAR MOTION

1.1

← Problem p. 4

Average speed is the total distance divided by the time; the magnitude of the average velocity is the magnitude of the displacement divided by the time. The total distance cannot be smaller than the magnitude of the displacement; if the particle does not reverse direction, the two are equal. **A** is correct.

- (B): A stone thrown upward is momentarily at rest at its highest point, but its acceleration is g.
- (C): Slowing down means that velocity and acceleration have *opposite signs*. A particle moving in the negative direction speeds up with a negative acceleration.
- (D): If the particle turns back, the distance is greater than the magnitude of the displacement.
- (E): In a braking vehicle, the velocity points forward and the acceleration points backward.

ANSWER A

1.2

← Problem p. 5

Velocity and acceleration are found by differentiation:

$$v = \frac{ds}{dt} = 6t^2 - 36t + 30 = 6(t-1)(t-5)\ \text{m/s},$$

$$a = \frac{dv}{dt} = 12t - 36\ \text{m/s}^2.$$

a. $v < 0$ for $1 < t < 5$ s; the particle reverses direction at $t = 1$ and $t = 5$ s. In this interval the speed is greatest at $t = 3$ s, where $a = 0$:

$$v(3) = 6(2)(-2) = -24.0\ \text{m/s},$$

so the greatest speed is 24.0 m/s.

b. Positions: $s(0) = 5$, $s(1) = 19$, $s(5) = -45$, $s(6) = -31$ m. Displacement:

$$\Delta s = s(6) - s(0) = -31 - 5 = -36\ \text{m}.$$

The total distance is found by splitting the motion at the instants of reversal:

$$d = |19-5| + |-45-19| + |-31-(-45)|$$
$$= 14 + 64 + 14 = 92\ \text{m}.$$

The average velocity is $-36/6 = -6.00$ m/s and the average speed is $92/6 = 15.3$ m/s. The two differ greatly because the particle turns back twice.

c. At $t = 6$ s

$$v = 6(5)(1) = 30.0\ \text{m/s},$$

$$a = 12(6) - 36 = 36.0\ \text{m/s}^2.$$

Velocity and acceleration have the same sign: the particle is speeding up.

ANSWER a. $1\ \text{s} < t < 5\ \text{s}$; 24.0 m/s
b. $\Delta s = -36$ m, $d = 92$ m, −6.00 m/s, 15.3 m/s
c. speeding up

1.3

← Problem p. 6

The direction of motion is positive.
$v_0 = 81/3.6 = 22.5$ m/s, braking acceleration $a = -6\ \text{m/s}^2$.

a. During the reaction time the car travels at constant velocity:

$$s_1 = v_0 t_r = 22.5(0.7) = 15.75\ \text{m}.$$

The braking distance from $0 = v_0^2 + 2a\,s_2$:

$$s_2 = \frac{22.5^2}{2(6)} = 42.19\ \text{m}.$$

Stopping distance $s_1 + s_2 = 57.9\ \text{m} > 50\ \text{m}$; the car cannot stop before the line and enters the intersection.

b. The distance left for braking is $50 - 15.75 = 34.25$ m:

$$v^2 = 22.5^2 - 2(6)(34.25) = 95.25 \implies v = 9.76\ \text{m/s},$$

that is, about 35.1 km/h.

c. The car must stop within 34.25 m:

$$|a|_{\min} = \frac{22.5^2}{2(34.25)} = 7.39\ \text{m/s}^2.$$

With the same braking the braking distance is 42.19 m, so the reaction distance can be at most

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$50 - 42.19 = 7.81$ m: $t_r = 7.81/22.5 = 0.347$ s. At this speed every 0.1 s of reaction time costs 2.25 m.

ANSWER a. 57.9 m, cannot stop b. 9.76 m/s c. 7.39 m/s^2; 0.347 s

1.4

← Problem p. 6

Upward is positive, with the origin at the ground. Both balls move with $a = -9.81$ m/s^2:

$$y_A = 14t - 4.905\,t^2, \qquad y_B = 24 - 4.905\,t^2.$$

a. For $y_A = y_B$ the $4.905\,t^2$ terms cancel: $14t = 24$, so $t = 24/14 = 1.71$ s.

$$y = 24 - 4.905(1.7143)^2 = 9.59 \text{ m}.$$

b. Velocities:

$$v_A = 14 - 9.81(1.7143) = -2.82 \text{ m/s},$$

$$v_B = -9.81(1.7143) = -16.8 \text{ m/s}.$$

$v_A < 0$: A has passed its highest point and is falling.

c. Time and height of A at the top:

$$t_{\text{peak}} = \frac{14}{9.81} = 1.427 \text{ s}, \quad h = \frac{14^2}{2(9.81)} = 9.990 \text{ m}.$$

Until it reaches this height, B falls $24 - 9.990 = 14.01$ m:

$$t_d = \sqrt{\frac{2(14.01)}{9.81}} = 1.690 \text{ s}.$$

The release instant of B is $1.427 - 1.690 = -0.263$ s. The minus sign shows that B must be released 0.263 s *before* A is thrown.

ANSWER a. $t = 1.71$ s, 9.59 m b. $v_A = 2.82$ m/s (↓, falling), $v_B = 16.8$ m/s (↓) c. 0.263 s earlier

1.5

← Problem p. 7

The direction of motion is positive, with the origin at the light; 54 km/h = 15 m/s. The car reaches the limit at $t_1 = 15/2.5 = 6$ s, traveling $x = \frac{1}{2}(2.5)(6)^2 = 45.0$ m in that time. The cyclist is then at $9(6) = 54$ m, still ahead.

a. In the accelerating phase the catch-up condition is $1.25\,t^2 = 9t$, so $t = 7.2$ s; this is greater than 6 s, so the car catches up in the constant-velocity phase:

$$45 + 15(t - 6) = 9t \implies 6t = 45,$$

$$t = 7.50 \text{ s}, \qquad x = 9(7.5) = 67.5 \text{ m}.$$

b. As long as the cyclist is ahead, the separation is $9t - 1.25\,t^2$. It is greatest when the velocities are equal: $2.5\,t = 9$, $t = 3.60$ s.

$$\Delta x = 9(3.6) - 1.25(3.6)^2 = 32.4 - 16.2 = 16.2 \text{ m}.$$

After this the car is faster and the gap begins to close.

ANSWER a. $t = 7.50$ s, 67.5 m b. 16.2 m ($t = 3.60$ s)

1.6

← Problem p. 8

The acceleration depends on time; integrate:

$$v = -7 + \int_0^t (8 - 2t)\,dt$$
$$= -7 + 8t - t^2 = -(t - 1)(t - 7),$$
$$s = \int_0^t v\,dt = -7t + 4t^2 - \frac{t^3}{3}.$$

a. $v = -(t - 1)(t - 7)$ is positive for $1 < t < 7$ s. The particle first moves in the negative direction, turns around at $t = 1$ s, and turns around again at $t = 7$ s.

b. The greatest velocity occurs when $a = dv/dt = 0$, at $t = 4$ s:

$$v_{\max} = -7 + 8(4) - 4^2 = 9.00 \text{ m/s}.$$

c. From the position relation:

$$s(7) = -7(7) + 4(7)^2 - \frac{7^3}{3}$$
$$= -49 + 196 - 114.3 = 32.7 \text{ m}.$$

The particle had first moved back as far as $s(1) = -3.33$ m.

ANSWER a. $1 \text{ s} < t < 7$ s b. 9.00 m/s, $t = 4$ s c. 32.7 m

1.7

← Problem p. 8

Downward is positive; $v = 0$, $s = 0$ at $t = 0$.

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