Matter & Interactions 2d Edition
Test Question Archive
Preliminary (incomplete) version

Chapter 2

September 23, 2007

The source for each problem is in a separate LaTeX file. See the file `02_problems.tex` for an example of how to assemble these problems into an exam. Sometimes homework problems are used as exam problems; these are not included.

Things you must know:

Definition of average velocity
Definition of momentum

The Momentum Principle

Other physical quantities:

$$\gamma \equiv \frac{1}{\sqrt{1 - \left(\frac{|\vec{v}|}{c}\right)^2}}$$

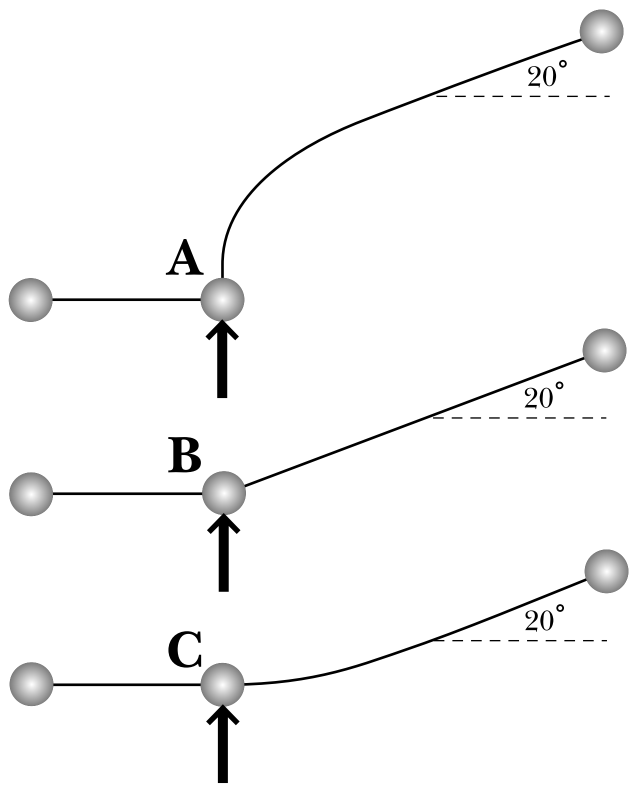
$\hat{f} = \langle \cos\theta_x, \cos\theta_y, \cos\theta_z \rangle$ unit vector from angles

Constant	Symbol	Approximate Value
Speed of light	c	3×10^8 m/s
Approx. grav field near Earth's surface	g	9.8 N/kg
Electron mass	m_e	9×10^{-31} kg
Proton mass	m_p	1.7×10^{-27} kg
Neutron mass	m_n	1.7×10^{-27} kg
Avogadro's number	N_A	6.02×10^{23} atoms/mol

milli	m	1×10^{-3}	kilo	K	1×10^{3}
micro	μ	1×10^{-6}	mega	M	1×10^{6}
nano	n	1×10^{-9}	giga	G	1×10^{9}
pico	p	1×10^{-12}	tera	T	1×10^{12}

001

A 0.6 kg basketball is rolling by you at 3.5 m/s. As it goes by, you give it a kick perpendicular to its path. Your foot is in contact with the ball for 0.002 s. The ball eventually rolls at a 20° angle from its original direction. The overhead view is approximately to scale. The arrow represents the force your toe applies briefly to the basketball.



(a) Circle the letter corresponding to the correct overhead view of the ball's path:

A B C

(b) Determine the magnitude of the average force you applied to the ball. You may if you wish make the approximation that the change in speed of the basketball is negligible.

A bird in flight is acted upon by the Earth and the air. Here are the positions of the bird at several times. Show all your calculations clearly!

Early time interval:
At $t = 4.46$ s, the position was $\langle 4.17, 3.54, -8.38 \rangle$ m
At $t = 4.49$ s, the position was $\langle 4.25, 3.50, -8.40 \rangle$ m

Late time interval:
At $t = 6.46$ s, the position was $\langle 12.25, 0.50, -10.40 \rangle$ m
At $t = 6.49$ s, the position was $\langle 12.27, 0.24, -10.42 \rangle$ m

(a) In the early time interval, from $t = 4.46$ s to $t = 4.49$ s, what was the average momentum of the bird? The mass of the bird is 70 grams (70×10^{-3} kg). Express your result as a vector.

(b) In the late time interval, from $t = 6.46$ s to $t = 6.49$ s, what was the average momentum of the bird? Express your result as a vector.

(c) In the time interval from $t = 4.46$ s (the start of the early time interval) to $t = 6.46$ s (the start of the late time interval), what was the average net force acting on the bird? Express your result as a vector.

A truck driver slams on the brakes and the momentum changes from $\left\langle 9 \times 10^4, 0, 0 \right\rangle$ kg $\cdot \frac{\text{m}}{\text{s}}$ to $\left\langle 3 \times 10^4, 0, 0 \right\rangle$ kg $\cdot \frac{\text{m}}{\text{s}}$ in 4 seconds due to a constant force of the road on the wheels of car. As a vector, write the force exerted by the road. Show your work.

Two students are running to classes in opposite directions. They run into each other head-on and stop abruptly. Using physics principles, estimate the force that one student exerts on the other during the collision. You will need to estimate some quantities; give reasons for your choices.

Two students are running to classes in opposite directions. They run into each other head-on and stop abruptly. Using physics principles, estimate the force that one student exerts on the other during the collision. You will need to estimate some quantities; give reasons for your choices and provide checks showing that your estimates are physically reasonable.

An electron initially has momentum $\left\langle 2.7 \times 10^{-24}, 0, 0 \right\rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$. At time $t = 0$, a constant force $\vec{F}$ is applied to the electron for 1×10^{-11} seconds. At time $t = 1 \times 10^{-11}$ seconds the momentum of the electron is $\left\langle 2.7 \times 10^{-24}, 0, -1.6 \times 10^{-24} \right\rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$. Calculate the force $\vec{F}$. Show your work.

An object of mass 0.5 kg has a momentum $\langle 2, 8, 5 \rangle$ kg $\cdot \frac{\text{m}}{\text{s}}$. At this instant the object is acted on by a force $\langle 20, -50, 75 \rangle$ N for 3×10^{-3} s (3 milliseconds). What is the momentum of the object at the end of this time interval? Show all your work.

An object had momentum $\langle 6, -4, 9 \rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$ when a net force $\langle 20, 10, -15 \rangle$ N started to act on the object. After 0.03 seconds, what was the new momentum of the object?

An object with mass 25 kg has a net force of $\langle -50, 0, 150 \rangle$ N acting on it. At $t = 15$ s, it has a momentum of $\langle -30, 20, 45 \rangle$ kg $\cdot \frac{\text{m}}{\text{s}}$.

(a) Determine the object's momentum at an earlier time $t = 10$ s. Start from a fundamental principle.

(b) If the position of the object is $\langle 0, -10, 25 \rangle$ m at $t = 10$ s, what is the new position of the object at $t =$ 15 s?

010

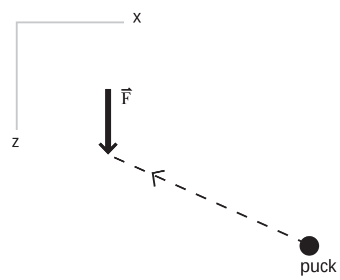
At a certain instant, a particle is moving in the $+x$ direction with momentum $+10\ \text{kg}\cdot\frac{\text{m}}{\text{s}}$. During the next 0.1 s, a constant force acts on the particle: $F_x = -6$ N, and $F_y = +3$ N. What is the magnitude of the momentum of the particle at the end of this 0.1 s interval?

011

The position of a golf ball relative to the tee changes from $\langle 50, 20, 30\rangle$ m to $\langle 53, 18, 31\rangle$ m in 0.1 second. As a vector, write the velocity of the golf ball during this short time interval. Show your work.

034

A hockey puck of mass 0.17 kg slides across the ice, traveling at constant speed in a straight line in the xz plane. At a particular time, the location of the puck is $\langle 18.5, 0, 9.2\rangle$ m, relative to an origin in the center of the ice rink. 0.2 seconds later, the location of the puck is $\langle 15.5, 0, 7.6\rangle$ m. When the puck reaches location $\langle 8, 0, 3.6\rangle$ m a player strikes it sharply with a hockey stick, exerting a force of $\langle 0, 0, 200\rangle$ N. The impact lasts 0.005 seconds.



What is the location of the puck at a time 0.5 seconds after the impact?

A hockey puck with mass 0.4 kg is sliding along the ice in the +x direction with speed 50 m/s. As the puck slides past location $\langle 5, 3, 0\rangle$ m on the rink, a player strikes the puck with a sudden force in the +y direction, and the hockey stick breaks. A short time later, the pucks position on the rink is $\langle 15, 11, 0\rangle$ m. When we pile weights on the side of a hockey stick we find that the stick breaks under a force of about 1000 N.

(a) For approximately how much time was the hockey stick in contact with the puck? Be sure to explain briefly the steps in your analysis.

(b) What approximations and/or simplifying assumptions did you make in your analysis?

A small space probe, of mass 264 kg, is launched from a spacecraft near Mars. It travels toward the surface of Mars, where it will land. 10.5 seconds after it is launched, the probe is at location $\langle 3.50 \times 10^3, 9.50 \times 10^2, 0 \rangle$ m, and its momentum is $\langle 3.80 \times 10^4, -9.80 \times 10^3, 0 \rangle$ kg $\cdot \frac{\text{m}}{\text{s}}$. At this instant, the net force on the lander due to the gravitational pull of Mars plus the air resistance acting on the probe is $\langle -8 \times 10^3, -9.3 \times 10^2, 0 \rangle$ N.

(a) Assuming that the net force on the probe is approximately constant over this time interval, what will be the momentum of the lander 10.8 seconds after it had left the spacecraft?

(b) What is the location of the probe 10.8 seconds after it had left the spacecraft?

015

A small space probe, of mass 240 kg, is launched from a spacecraft near Mars. It travels toward the surface of Mars, where it will land. 20.7 seconds after it is launched, the probe is at location $\langle 4.3 \times 10^3, 8.7 \times 10^2, 0 \rangle$ m, and its momentum is $\langle 4.40 \times 10^4, -7.60 \times 10^3, 0 \rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$. At this instant, the net force on the lander due to the gravitational pull of Mars plus the air resistance acting on the probe is $\langle -7 \times 10^3, -9.2 \times 10^2, 0 \rangle$ N.

(a) Assuming that the net force on the lander is approximately constant over this time interval, what is the momentum of the lander 20.9 seconds after it is launched?

(b) What is the location of the lander 20.9 seconds after launch?

A small space probe, of mass 425 kg, is launched from a spacecraft near Mars. It travels toward the surface of Mars, where it will land. At a time, 30.6 seconds after it is launched, the probe is at location $\langle 4.6 \times 10^3, 8.4 \times 10^2, 0 \rangle$ m, and its momentum is $\langle 5.2 \times 10^4, -8.7 \times 10^3, 0 \rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$. At this instant, the net force on the lander due to the gravitational pull of Mars plus the air resistance acting on the probe is $\langle -6 \times 10^3, -5.2 \times 10^2, 0 \rangle$ N.

(a) What is the location of the probe 30.9 seconds after launch? Show your work.

(b) Assuming that the net force on the probe is approximately constant over this time interval, what is the momentum of the lander 30.9 seconds after it is launched? Show your work.

A small space probe, of mass 264 kg, is launched from a spacecraft near Mars. It travels toward the surface of Mars, where it will land. 0.5 seconds after it is launched, the probe is at location $\langle 3.5 \times 10^3, 9.5 \times 10^2, 0 \rangle$ m, and its momentum is $\langle 1.9 \times 10^6, -4.9 \times 10^5, 0 \rangle$ $\text{kg} \cdot \frac{\text{m}}{\text{s}}$. At this instant, the net force on the lander due to the gravitational pull of Mars plus the air resistance acting on the probe is $\langle -8 \times 10^3, -9.3 \times 10^2, 0 \rangle$ N.

(a) Assuming that the net force on the lander is approximately constant over this time interval, what is the momentum of the lander 0.8 seconds after it is launched?

(b) What is the location of the lander 0.8 seconds after launch?

018

(a) State the momentum principle in words.

(b) State the momentum principle mathematically.

(a) Write down the definition of the momentum of a particle valid at all speeds. Please define any auxiliary quantities you use. Your answer must be exactly correct to receive credit, including arrows for vectors, correct subscripts, etc. There is no partial credit.

(b) Write down any **one** of the valid forms of the momentum principle. If you write more than one and any of them are incorrect, the whole problem will be marked as incorrect. Your answer must be exactly correct to receive credit, including arrows for vectors, correct subscripts, etc. There is no partial credit.

(c) A VPython program has created two spheres named `star` and `planet`. Write a statement to create an arrow whose tail is at the location of the star and whose tip is located at the planet.

019

A billiard ball on a billiards table has a momentum $\langle 3, 0, 4 \rangle \;\; \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}}$. When a stick strikes the ball, a net force of $\langle 10, 4, -3 \rangle$ N acts on the billiard ball for 0.1 s. According to the momentum principle, the change in momentum of the billiard ball and the net force on the billiard ball

(a) are in opposite directions.

(b) are in the same direction.

(c) are not necessarily in the same or opposite directions, but can be.

A billiard ball on a billiards table has a momentum $\langle 3, 0, 4\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$. When a stick strikes the ball, a net force of $\langle 10, 4, -3\rangle$ N acts on the billiard ball for 0.1 s. What is the final momentum of the ball after it is struck?

(a) $\langle 4, 0.4, 3.7\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$

(b) $\langle 0.1, 0.4, -0.3\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$

(c) $\langle 0.3, 0, 0.4\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$

(d) $\langle 7, 0, -7\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$

(e) $\langle 13, 4, 1\rangle$ $\text{kg}\cdot\frac{\text{m}}{\text{s}}$

A ping-pong ball with mass 2.7 grams (2.7×10^{-3} kg) is acted upon by the Earth, air resistance, and a strong wind. Here are the positions of the ball at several times.

At $t = 12.35$ s, the position was $\langle 3.17, 2.54, -9.38 \rangle$ m
At $t = 12.40$ s, the position was $\langle 3.38, 2.44, -9.42 \rangle$ m
At $t = 12.45$ s, the position was $\langle 3.54, 2.32, -9.46 \rangle$ m

(a) In the first time interval, from $t = 12.35$ s to $t = 12.40$ s, what was the average momentum of the ball?

(b) In the second time interval, from $t = 12.40$ s to 12.45 s, what was the average momentum of the ball?

(c) In the time interval from $t = 12.375$ s to $t = 12.425$ s (that is, from the midpoint of the first time interval to the midpoint of the second time interval), what was the average force acting on the ball?

A ping-pong ball is acted upon by the Earth, air resistance, and a strong wind. Here are the positions of the ball at several times.

Early time interval:

At $t = 12.35$ s, the position was $\langle 3.17, 2.54, -9.38 \rangle$ m

At $t = 12.37$ s, the position was $\langle 3.25, 2.50, -9.40 \rangle$ m

Late time interval:

At $t = 14.35$ s, the position was $\langle 11.25, -1.50, -11.40 \rangle$ m

At $t = 14.37$ s, the position was $\langle 11.27, -1.86, -11.42 \rangle$ m

(a) In the early time interval, from $t = 12.35$ s to $t = 12.37$ s, what was the average momentum of the ball? The mass of the ping-pong ball is 2.7 grams (2.7×10^{-3} kg).

(b) In the late time interval, from $t = 14.35$ s to $t = 14.37$ s, what was the average momentum of the ball?

(c) In the time interval from $t = 12.35$ s (the start of the early time interval) to $t = 14.35$ s (the start of the late time interval), what was the average net force acting on the ball?

A proton moving along the x axis interacts electrically with a neutral HCl molecule located at the origin with a force that is approximately equal to $\frac{w}{x^3}$, where w is a constant.

(a) When the proton's position is $\left\langle 8 \times 10^{-10}, 0, 0 \right\rangle$ m, the HCl molecule exerts a force $\left\langle 9 \times 10^{-11}, 0, 0 \right\rangle$ N on the proton. Calculate w. Include appropriate units.

(b) Later, at a certain time t, the proton's position is $\left\langle 1.6 \times 10^{-9}, 0, 0 \right\rangle$ m and the proton's velocity is $\langle 3200, 800, 0 \rangle$ m/s. At a time $t + \left(2 \times 10^{-14}\ \text{s}\right)$, what is the approximate position of the proton, and what is its approximate velocity?

A proton interacts electrically with a neutral HCl molecule located at the origin. At a certain time t, the proton's position is $\langle 1.8 \times 10^{-9}, 0, 0 \rangle$ m and the proton's velocity is $\langle 3300, 900, 0 \rangle$ m/s. The force exerted on the proton by the HCl molecule is $\langle -1.12 \times 10^{-10}, 0, 0 \rangle$ N.

At a time $t + \left(3 \times 10^{-14} \text{ s}\right)$, what is the approximate position of the proton, and what is its approximate velocity? Show your work.

A proton interacts electrically with a neutral HCl molecule located at the origin. At a certain time t, the proton's position is $\langle 1.6 \times 10^{-9}, 0, 0 \rangle$ m and the proton's velocity is $\langle 3200, 800, 0 \rangle$ m/s. The force exerted on the proton by the HCl molecule is $\langle -1.12 \times 10^{-11}, 0, 0 \rangle$ N. At a time $t + \left(2 \times 10^{-14} \text{ s}\right)$, what is the approximate velocity of the proton? Show your work.

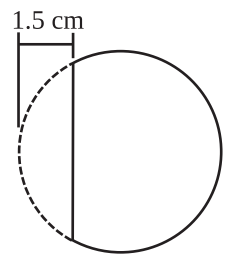
You are working as a consultant to a theme park. You job is to ensure the safety of the children's rides. Fortunately, you have knowledge and experience in physics, human anatomy and physiology, and computers so that you can calculate the net force on a child, write a simulation, and understand whether the strain on a child's body will be too much to be healthy. For this particular project, you are studying a children's roller coaster.

(a) A child of mass 20 kg who is riding the roller coaster has a speed of 5 m/s in the direction $\langle 1, 0, 0 \rangle$. What is the momentum of the child? (Remember that momentum is a vector and should be expressed in component form.)

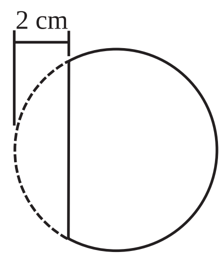
(b) Two seconds later, the child's velocity is 3 m/s in the direction $\langle 0.333, 0.667, 0.667 \rangle$. What was the net force on the child during this time interval? (You already know the child's initial momentum, but you will need to first calculate the final momentum of the child. Remember that net force is a vector and should be expressed in component form.)

A hockey puck with mass 0.4 kg is sliding along the ice in the $+x$ direction with speed 40 m/s. As the puck slides past the center of the rink, a player strikes the puck with a sudden force in the $+y$ direction, with magnitude 8×10^4 N. The contact between hockey stick and puck lasts only 1.2 milliseconds $\left(1.2 \times 10^{-3}\ \text{seconds}\right)$. At a time 0.3 seconds later, where is the puck, and what is its speed? (Let the center of the rink be the origin. Friction between puck and ice is negligible.)

A tennis ball has a mass of 0.06 kg. A professional tennis player hits the ball hard enough to give it a speed of 45 m/s (about 100 miles per hour). The ball hits a wall and bounces back with almost the same speed (45 m/s). As indicated in the diagram, high-speed photography shows that the ball is crushed 1.5 cm (0.015 m) at the instant when its speed is momentarily zero, before rebounding. Determine the approximate force that the wall exerts on the ball.



A tennis ball has a mass of 0.057 kg. A professional tennis player hits the ball hard enough to give it a speed of 50 m/s (about 120 miles per hour). The ball hits a wall and bounces back with almost the same speed (50 m/s). As indicated in the diagram, high-speed photography shows that the ball is crushed 2 cm (0.02 m) at the instant when its speed is momentarily zero, before rebounding.

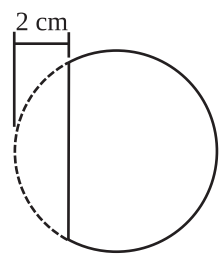


Making the very rough approximation that the large force that the wall exerts on the ball is approximately constant during contact, determine the approximate magnitude of this force. Hint: Think about the approximate amount of time it takes for the ball to come momentarily to rest.

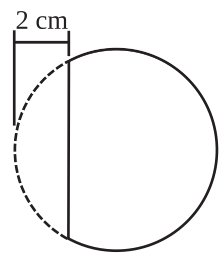
A hard hit tennis ball may travel at a speed of about 50 m/s (about 110 miles per hour). Its mass is 57 grams (0.057 kg). Estimate the magnitude of the force exerted on the tennis ball when it hits a rigid wall and bounces back with its speed nearly unchanged. Explain carefully what approximations or simplifying assumptions you make.

032

A tennis ball has a mass of 0.057 kg. A professional tennis player hits the ball hard enough to give it a speed of 50 m/s (about 120 miles per hour). The ball hits a wall and bounces back with almost the same speed. As indicated in the diagram, high-speed photography shows that the ball is crushed 2 cm (0.02 m) at the instant when its speed is momentarily zero, before rebounding. Determine the approximate force that the wall exerts on the ball.



A tennis ball has a mass of 0.057 kg. A professional tennis player hits the ball hard enough to give it a speed of 50 m/s (about 120 miles per hour). The ball hits a wall and bounces back with almost the same speed (50 m/s). As indicated in the diagram, high-speed photography shows that the ball is crushed 2 cm (0.02 m) at the instant when its speed is momentarily zero, before rebounding.



Making the very rough approximation that the large force that the wall exerts on the ball is approximately constant during contact, determine the approximate magnitude of this force. Hint: Think about the approximate amount of time it takes for the ball to come momentarily to rest. (For comparison note that the gravitational force on the ball is quite small, only about $(0.057\,\text{kg})\left(9.8\frac{\text{N}}{\text{kg}}\right) \approx 0.6\,\text{N}$. A force of 5 N force is approximately the same as a force of one pound.) Show your work.

In a crash test, a truck with mass 2200 kg traveling at 25 m/s (about 55 miles per hour) smashes head-on into a concrete wall without rebounding. The front end crumples so much that the car is 0.8 m shorter than before. Estimate the magnitude of the force exerted on the truck by the wall. Explain your analysis carefully, and justify your estimate on physical grounds.

035

The z-component of the momentum of a ball is observed to change with time.

At $t = 0$ s, $p_z = 12$ kg $\cdot$ m/s
At $t = 1$ s, $p_z = 7$ kg $\cdot$ m/s
At $t = 2$ s, $p_z = 2$ kg $\cdot$ m/s
At $t = 3$ s, $p_z = -3$ kg $\cdot$ m/s

Which of the following statements about the z component of the net force acting on the ball during the time the ball is observed is true?

A. The z component of the net force on the ball is zero.

B. The z component of the net force on the ball is constant.

C. The z component of the net force on the ball is changing with time.

D. Not enough information is given to determine the z component of the net force on the ball.