Chapter 7 – Newton's 3rd Law

- Interacting objects
  - objects in contact with each other
- Newton's 3rd Law
  - action/reaction pairs of forces
  - action/reaction forces act on <u>different</u> objects
- Ropes and pulleys
  - objects connected by ropes (tension)
  - pulleys change direction of force

PHYS 22, Chap. 26, Pg 1

1

Newton's 3rd Law

2

Newton's Third Law

Is boxing glove A hitting glove B, or is glove B hitting glove A?

The gloves hit each other

For every action there is an equal and opposite reaction.

For the boxing gloves:

Action: A pushes on B

Reaction: B pushes on A

$$F_{A\ on\ B} = -F_{B\ on\ A}$$

Action and Reaction forces:

- have the same magnitude
- are in opposite directions
- act on different objects

How Things Work: Sec. 1.3, Pg 3

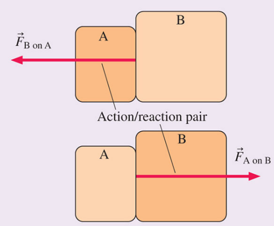
3

Newton's Third Law

Every force occurs as one member of an **action/reaction** pair of forces. The two members of an action/reaction pair:

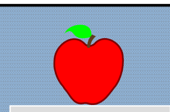
- act on two *different* objects.
- point in opposite directions and are equal in magnitude:

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$



4

Forces Present:



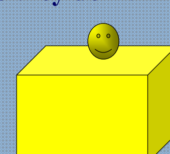
- What is one of the forces present?
  - Force of Earth on apple (gravity → weight)
- What is the reaction force to this?
  - Force of apple on Earth (gravity)
- These two forces are an <u>action-reaction pair</u>

How Things Work: Sec. 1.3, Pg 5

5

Two Crucial Notes:

- While the forces two objects exert on each another must be equal and opposite, the net force on each object can be anything.
- Each force within an <u>action-reaction pair</u> is exerted on a <u>different object</u>, so they don't cancel directly.
- In other words, forces in an action-reaction pair appear in different free-body diagrams.

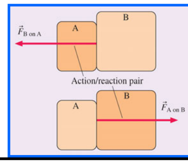


How Things Work: Sec. 1.3, Pg 6

6

Things to keep in mind for Newton's 3rd Law

- Every force occurs as one member of an action/reaction pair. The two forces always act on *different* objects.
- You should draw a *separate* free-body diagram (FBD) for each object of an interacting pair.
- In the FBD for each object, only show the forces acting on *that object*. The force F_{AonB} goes on the FBD of object B, while the other force F_{BonA} goes on the FBD of object A.
- The two members (forces) of an action/reaction pair are equal in magnitude and opposite in direction.
- The two members (forces) of an action/reaction pair always appear on *different* FBD's (never on the same diagram).



7

Draw the objects for each of the cases below. Draw the force vectors on all action/reaction pairs and label the vectors like F_{AonB}.

1) A girl pushes a box across the floor.
Friction is not negligible.
The objects are the girl, the box and the floor.

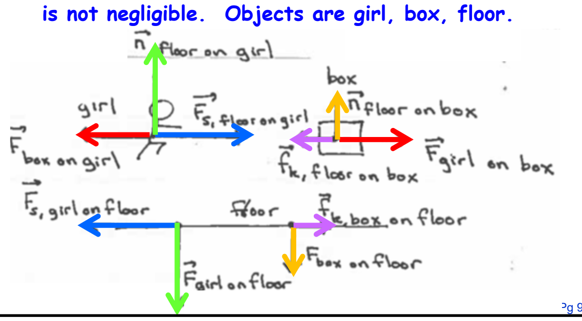
2) A crate is in the back of a pickup truck, as the truck accelerates forward. The crate does not slip.
The objects are the truck, the crate and the ground.

4.24-4.25 PHYS 11: Chap. 4, Pg 8

8

Draw the objects for each of the cases below. Draw the force vectors on all action/reaction pairs and label the vectors like F_{AonB}.

1) A girl pushes a box across the floor. Friction is not negligible. Objects are girl, box, floor.

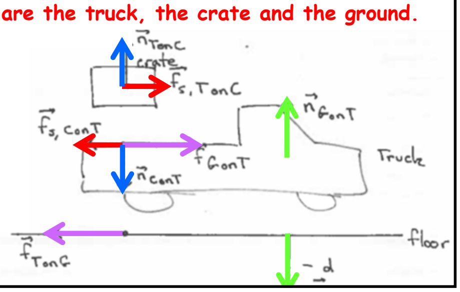


Pg 9

9

Draw the objects for each of the cases below. Draw the force vectors on all action/reaction pairs and label the vectors like F_{AonB}.

2) A crate is in the back of a pickup truck, as the truck accelerates forward. The crate does not slip. The objects are the truck, the crate and the ground.

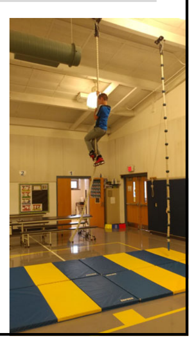


10

You find yourself in the middle of a frozen lake with a very slippery surface – so slippery that you cannot walk. However, you happen to have several rocks in your pocket. Can you think of a way to get to shore?

How do basketball players jump up in the air?

How do you climb up the rope in gym class?



4.26-4.27

11

ConcepTest 1 — Newton's 3rd Law

You are standing at rest on the floor. What is the "reaction force" to your weight?

1. normal force exerted by the floor
2. gravitational force exerted by the Earth
3. none of the above

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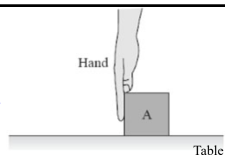
12

Block A is being pushed across a rough horizontal surface at *constant speed* by a hand that exerts a force (call it F_{HonA}).



a) Draw a free-body diagram for the block. All force vectors should be scaled appropriately.

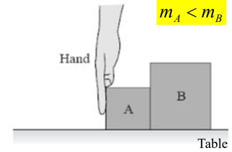
b) Rank all of the horizontal forces in your diagrams. This should be consistent with the lengths of the vectors in Part (a). $(F_{HonA}=F_{AonH}) = F_{TonA}$

c) Now repeat the above parts for the case in which the block is *speeding up*. $(F_{HonA}=F_{AonH}) > F_{TonA}$

13

Blocks A and B are being pushed across a frictionless horizontal surface by a hand. The blocks are *speeding up*.

$m_A < m_B$



a) Draw free-body diagrams for both blocks. All force vectors should be scaled appropriately.

b) Rank all of the horizontal forces in your diagrams. This should be consistent with the lengths of the vectors in Part (a). $F_{HonA} > (F_{AonB}=F_{BonA})$

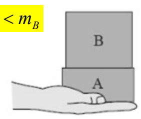
c) Now repeat the above parts for the case in which there is friction on the surface.

$F_{HonA} > (F_{AonB}=F_{BonA}) > f_{TonB} > f_{TonA}$

14

Blocks A and B are held on the palm of your hand as you lift them upwards at *constant speed*.

$m_A < m_B$



a) Draw free-body diagrams for both blocks. All force vectors should be scaled appropriately.

b) Rank all of the vertical forces in your diagrams. This should be consistent with the lengths of the vectors in Part (a).

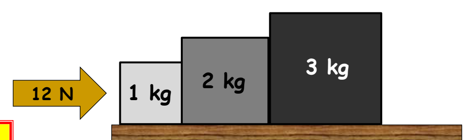
$(F_{HonA}=F_{AonH}) > (F_{AonB}=F_{BonA}) = W_{EonB} > W_{EonA}$

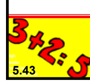
15

Three blocks are lined up on a frictionless table. All three are pushed forward by a 12 N force applied to the 1 kg block.

(a) How much force does the 2 kg block exert on the 3 kg block? F_{2on3} = 6 N

(b) How much force does the 2 kg block exert on the 1 kg block? F_{2on1} = 10 N





16

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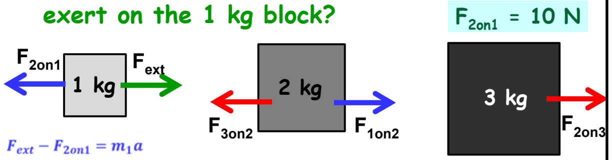


$F_{ext} - F_{2on1} = m_1 a$

$F_{2on1} = F_{ext} - m_1 a = 12N - 2\,N = 10\,N$

$F_{1on2} - F_{3on2} = m_2 a$

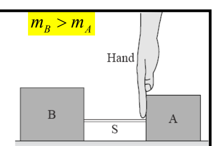
$F_{2on3} = m_3 a = 6\,N$

$a = \frac{F_{ext}}{M_{tot}} = \frac{12N}{6kg} = 2\,\frac{m}{s^2}$

17

Blocks A and B are connected by a string. The hand pushing on the back of A *accelerates* them along a frictionless surface.

$m_B > m_A$



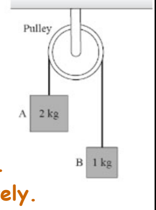
a) Draw free-body diagrams for both blocks. All force vectors should be scaled appropriately.

b) Rank all of the horizontal forces in your diagrams. This should be consistent with the lengths of the vectors in Part (a).

$F_{HonA} > (F_{SonA}=F_{AonS}) = (F_{SonB}=F_{BonS})$

18

Blocks A and B are connected by a string over a frictionless pulley. The blocks have just been released.



a) Do the blocks accelerate? Which way?

b) Draw free-body diagrams for both blocks. All force vectors should be scaled appropriately.

c) Rank all of the vertical forces in your diagrams. This should be consistent with the vector lengths in Part (b).

d) Consider the block that falls. Is its acceleration less than, greater than, or equal to g?

e) Compare the size of the net force on the blocks. Are they equal or is one larger than the other?

5.33

PHYS 21: Chap. 7, Pg 19

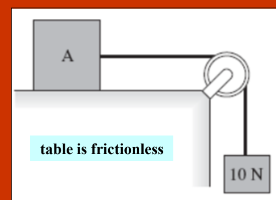
19

ConcepTest 1a Ropes and Pulleys

Block A is accelerated on a frictionless table by a hanging weight of 10 N.

What is the tension in the string?

1. T > 10 N
2. T = 10 N
3. T < 10 N



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PHYS 21: Chap. 6, Pg 20

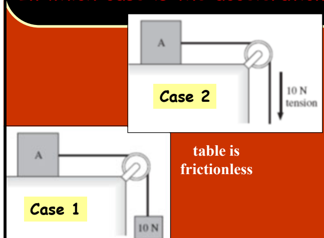
20

ConcepTest 1b Ropes and Pulleys

In case (1), block A is accelerated by a hanging weight of 10 N.
In (2), block A is accelerated by a constant 10 N tension in a string.

1. case 1
2. case 2
3. both the same

In which case is the acceleration of block A greater?



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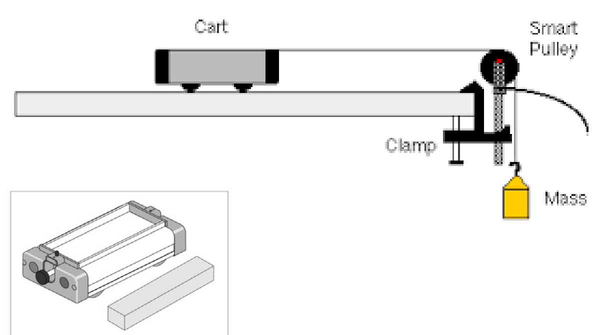
PHYS 21: Chap. 6, Pg 21

21

Let's try it…

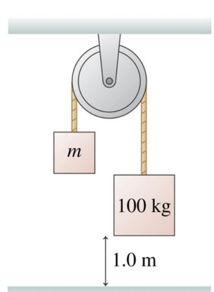


PHYS 21: Chap. 6, Pg 22

22

An Atwood's machine is shown in the figure. The 100 kg block on the right side takes 6.0 s to reach the floor after it is released from rest.

What is the mass of the block on the left side?



m = 99 kg

3+2:3

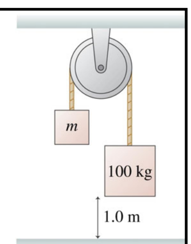
7.38

PHYS 21: Chap. 7, Pg 23

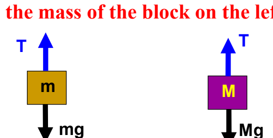
23

An Atwood's machine is shown in the figure. The 100 kg block on the right side takes 6.0 s to reach the floor after it is released from rest.

What is the mass of the block on the left side?



SOLUTION



$$\sum F_y = T - mg = ma \qquad \sum F_y = T - Mg = -Ma$$

$$T = mg + ma \qquad T = Mg - Ma$$

$$mg + ma = Mg - Ma$$

$$m = M\frac{g-a}{g+a} = 99kg$$

$$y = \tfrac{1}{2}at^2$$

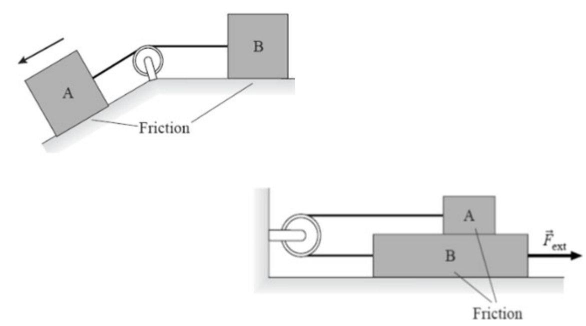
$$a = \frac{2y}{t^2}$$

$$= 0.056 m/s^2$$

PHYS 21: Chap. 7, Pg 24

24

Draw separate free-body diagrams for A and B.



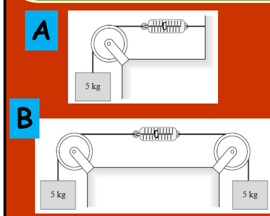
7.26-27

25

ConcepTest 1 Ropes and Pulleys

Compare the spring scale readings in the two cases below. Which case has the larger scale reading, or are they both the same?

1. A > B
2. A < B
3. A = B



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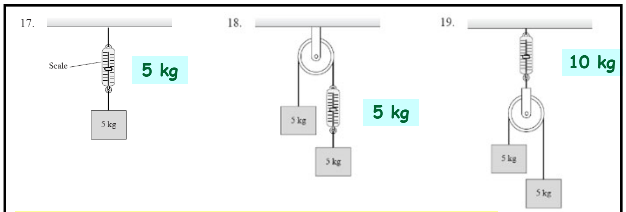
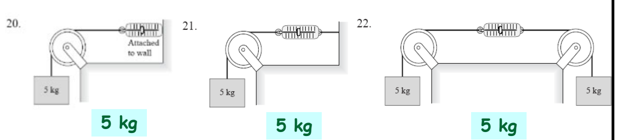
26



Determine the reading of the spring scales. All scales read in kg. All masses are at rest.



7.17-22

27

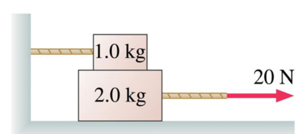
A **1.0 kg** block is tied to the wall with a rope. It sits on top of a **2.0 kg** block. The lower block is being pulled to the right with a tension force of **20 N**. The coefficient of kinetic friction at both the lower and upper surfaces of the 2.0 kg block is $\mu_k = 0.40$.

What is the tension in the rope attached to the 1.0 kg block?

What is the acceleration of the 2.0 kg block?

$T_1 = 3.92$ N

$a_2 = 2.16$ m/s^2



3+2:3

7.33

28

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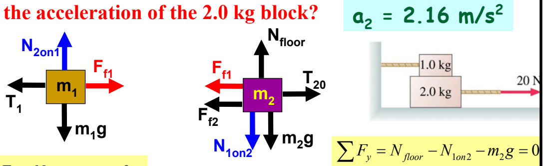
$T_1 = 3.92$ N

What is the tension in the rope attached to the 1.0 kg block?

What is the acceleration of the 2.0 kg block? $a_2 = 2.16$ m/s^2



SOLUTION

$\sum F_y = N_{2on1} - m_1 g = 0$

$\sum F_x = F_{f1} - T_1 = \mu_k N_{2on1} - T_1 = 0$

$T_1 = \mu_k F_{f1} = \mu_k N_{2on1}$

$= \mu_k m_1 g = 3.92N$

$\sum F_y = N_{floor} - N_{1on2} - m_2 g = 0$

$N_{floor} = (m_1 + m_2)g$

$\sum F_x = T_{20} - F_{f1} - F_{f2} = m_2 a_2$

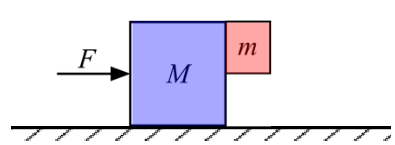
$20 - \mu_k N_{1on2} - \mu_k N_{floor} = m_2 a_2$

$20 - \mu_k (2m_1 + m_2)g = m_2 a_2$

$a_2 = 2.16 m/s^2$

29

A small block of **mass *m*** is pushed by a larger block of **mass *M***, which itself rests on a flat frictionless table. If the coefficient of static friction between the two blocks is μ_s, find the **minimum horizontal force *F*** that can be applied such that the **mass *m*** does not slide downward.



3+2:3

30

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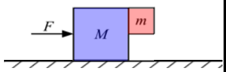
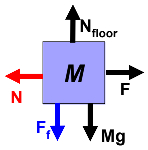
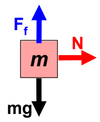


SOLUTION





$$\sum F_x = N = ma$$

$$\sum F_y = F_{fric} - mg = \mu_s N - mg = 0$$
$$= \mu_s ma - mg = 0$$

$$a = \frac{g}{\mu_s}$$

$$N = ma = \frac{mg}{\mu_s}$$

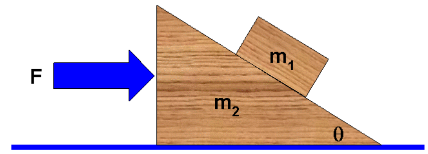
$$\sum F_x = F - N = Ma$$

$$F = N + Ma = (M+m)\frac{g}{\mu_s}$$

31

What horizontal force F must be applied to the wedge such that the mass m_1 does not slip either up or down along the surface of the plane? All surfaces are frictionless.

$F_{push} = (m_1+m_2)\, g \tan\theta$



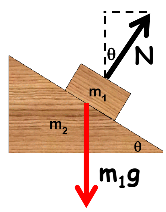
3+2.5

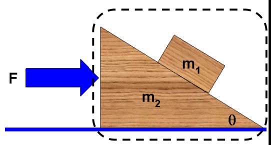
32

What horizontal force F must be applied to the wedge such that the mass m_1 does not slip either up or down along the surface of the plane? All surfaces are frictionless.

$F_{push} = (m_1+m_2)\, g \tan\theta$

SOLUTION





$$\begin{cases} N\cos\theta = m_1 g \\ N\sin\theta = m_1 a \end{cases}$$

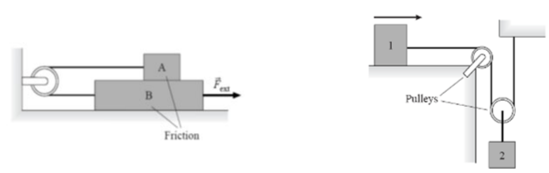
$$a = g\tan\theta$$

$$F = (m_1+m_2)a$$

$$= (m_1+m_2)\, g\tan\theta$$

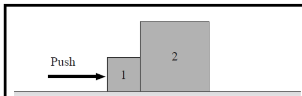
33

Write acceleration constraints using components. For example, $(a_1)_x = (a_2)_y$.

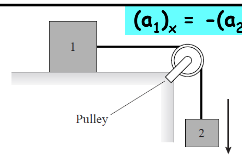


7.16,23,26,27

34

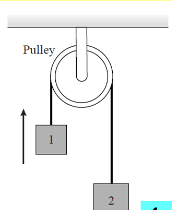


$(a_1)_x = (a_2)_x$

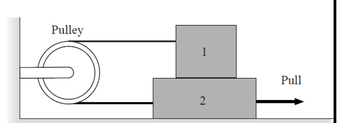


$(a_1)_x = -(a_2)_y$

Write acceleration constraints using components. For example, $(a_1)_x = (a_2)_y$.



$(a_1)_y = -(a_2)_y$

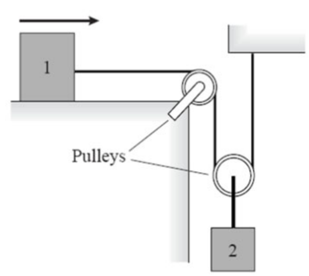


$(a_2)_x = -(a_1)_x$

7.12-15

35

Write acceleration constraints using components. For example, $(a_1)_x = (a_2)_y$.



$(a_1)_x = -2(a_2)_y$

7.16

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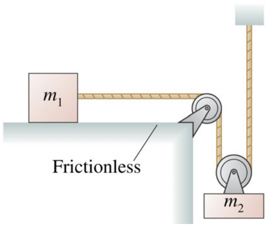
Find an expression for the acceleration of m_1.



3+2:3

7.54

$$a_1 = \frac{m_2 g}{\frac{1}{2} m_2 + 2m_1}$$

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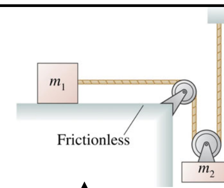
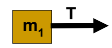
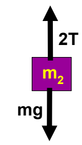
Find an expression for the acceleration of m_1.



$$a_1 = \frac{m_2 g}{\frac{1}{2} m_2 + 2m_1}$$

SOLUTION





$$\sum F_x = T = m_1 a_1$$

$$\sum F_y = m_2 g - 2T = m_2 a_2 = m_2\left(\frac{a_1}{2}\right)$$

$$m_2 g - 2(m_1 a_1) = m_2\left(\frac{a_1}{2}\right) \Rightarrow a_1 = \frac{m_2 g}{\frac{1}{2} m_2 + 2m_1}$$

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