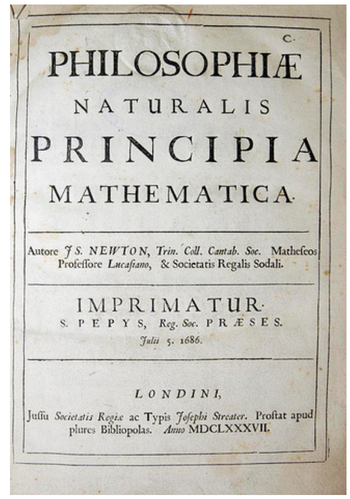
# 11th Physics　3　　　The Laws of Motion　　　2019-20



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Mathefeos Profeffore Lucafiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Juffu Societatis Regiæ ac Typis Jofephi Streater. Proftat apud plures Bibliopolas. Anno MDCLXXXVII.

Newton's "Principia" (1687)

We are all subject to Newton's laws of motion, whether we know it or not.　You can't move your body, drive a car, or toss a ball in a way that violates his rules.

Yet Newton's laws are surprisingly simple, especially when you consider that they apply equally well to galaxies, planets, comets, and yes, even apples falling from trees.

Today, we still recognize Newton's laws as the indispensable foundation for all of physics.　It would be nice to say that these laws are the complete story when it comes to analyzing motion, but that is not the case.　In the earlypart of the last century, physicists discovered that Newton's laws must be modified for objects moving at speeds near that of light and for objects comparable in size to atoms.　In the world of everyday experience, however, Newton's laws still reign supreme.　(James S. Walker, "Physics", 2010 Pearson Education Inc.)

**Newton's First Law of Motion:**
**An object at rest remains at rest as long as no net force acts on it.**
**An object moving with constant velocity continues to move with the same speed in the same direction as long as no net force acts on it.**

## 1 . Newton's First Law ( The Law of Inertia )

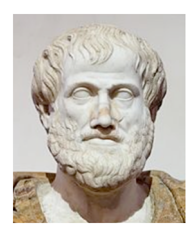
### A. Before Galileo

[Q1] Primitive basic questions:

1. Is a force always required to move an object continuously, as a horse is required to move wagon continuously?

2. Similarly, when you push a toy car, it moves in a straight line but gradually slows down and come to rest. Does this mean that a force is required to move a toy car continuously?

3. Aristotle, a Greek philosopher and scientist, believed that objects only moved as long as they were pushed or pulled. Thus, objects on the Earth stopped moving once applied forces were removed, and the heavenly spheres only moved because of the action of the Prime Mover, who continuously applied the force to the outer spheres that turned the entire heavens. However, any force seems not to act on a flying arrow. How do you think he explained about this phenomenon?



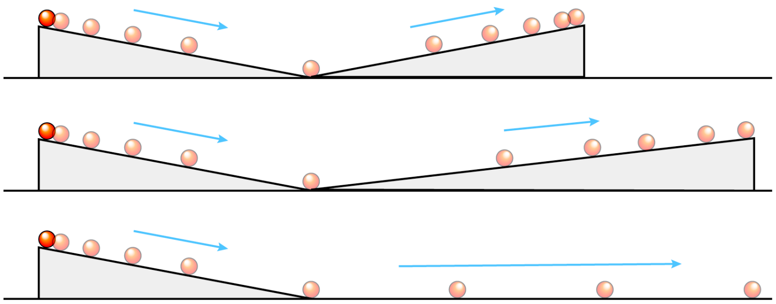
Aristotle(384BC-322BC)

Flying arrow

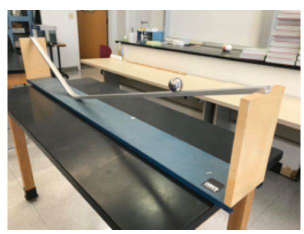
## B. Galileo's Observations and "Inertia"

Galileo Galilei (1564-1642)

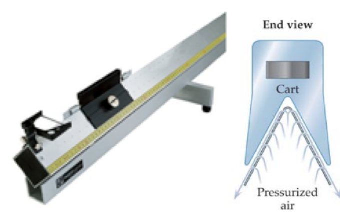
[Q2] Galileo Galilei observed a marble ball rolling on slopes, shown below, and found that the marble rolled down the plane and the opposite plane approximately the same height.
Then he repeated similar experiments while the second hill was less and less steep and horizontal finally. The marble rolling horizontally moved with the same speed in the same direction.　He thought it would roll forever if any friction acted it.
He concluded that a body naturally tends to continue in whatever state of motion or rest it is at any instant and tends to resist any changes.　***The extent to which a body resists changes in its state of rest or motion is characteristic of the body and is called its <u>inertia</u>***: the literal meaning of the word ***inertia*** is "**<u>laziness</u>**."



[Mini-Lab #30]　The Law of Inertia

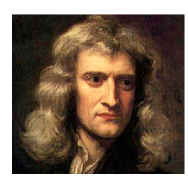


(a) Ball on slopes




(b) Air track

## C. Newton's First Law of Motion　(The Law of Inertia)



Isaac Newton　　(1642-1727)

[Q5] **Newton's first law of motion**, first enunciated by Galileo, summarizes the above observations in the following statements:

---

An object at rest remains at rest as long as no net force acts on it.

An object moving with constant velocity continues to move with the same speed and the same direction as long as no net force acts on it.

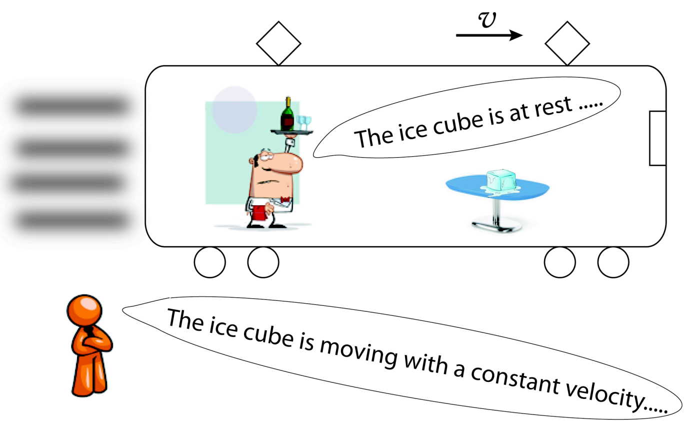
---

[Q6] In the statements, a phrase, "no net force" is recurred.　It is important to realize that this can mean one of two things. What are the two things?

[Q7] Newton's first law is also known as the **<u>law of inertia</u>**.　Explain the word, "inertia."

[Mini-Lab #31] A rock on a table

[Q8] According to Newton's first law, being at rest and moving with constant velocity are actually equivalent. Explain this using the figure at the right, where a person in the train moving with constant velocity places an ice cube on a dinner table.




[Q9] Explain the above question using the words, "frame of reference" and "inertial frame."

[Q10] Explain about "Galilean relativity."

[Q11] **Newton's first law of motion** can be restated in a more compact statement as follows:

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If the net force on an object is zero, its velocity is constant.

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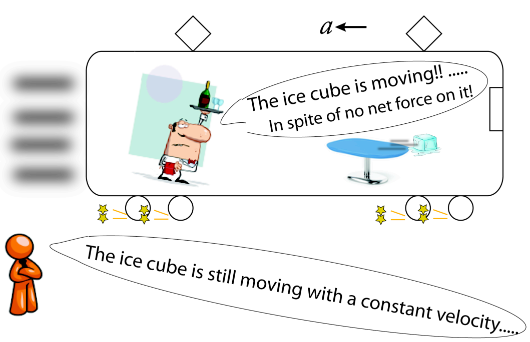
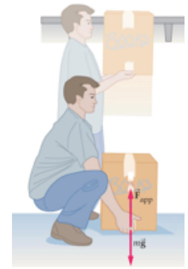
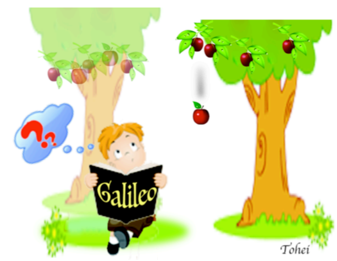
[Q12] As an example of a frame that is not inertial, consider the train that suddenly comes to a halt in the figure. Explain.



[Q13] A 10 kg box is lifted vertically from rest. Find the magnitude of the minimum force, F, required to lift the box. Explain.



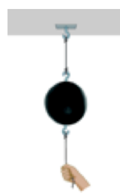
[Q14] In the figure, Newton is watching an apple falling and wondering why it falls. How do you think he reached such a question, the idea nobody took into one's mind?



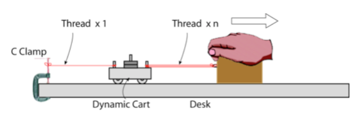

[Q15] The following figures can also be explained using the concept of inertia. Discuss.


f) Daruma

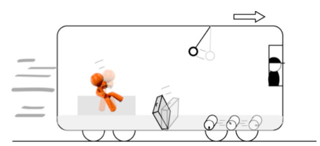

g) Coin on a cardboard


h) Hanging iron


i) Rug beating

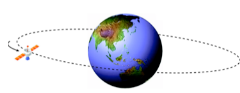


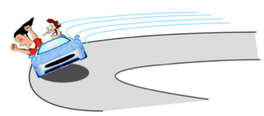
j) Cart pulling


k) Jump start


l) Fixing a loose head


m) Head-on collision

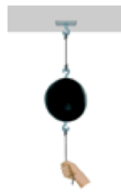

o) Satellite

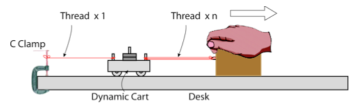

p) Sharp curve


q) Roller coaster

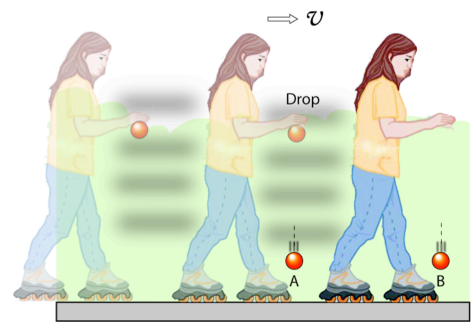

r) Shakes the wet body

[Mini-Lab 32]　The Law of Inertia






f) Daruma　g) Coin on a cardboard　h) Hanging iron j) Cart pulling




## D. Motion in an inertial frame

[Q21] When you skate with a constant velocity, 5.0 m/s, you release a ball softly. Where does the ball drop?　(A) Behind you. (B) Just under your hand.　E

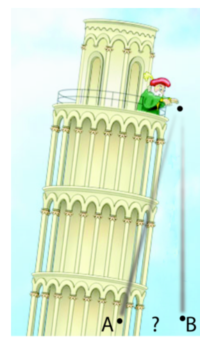



Fig. a

[Q22] Scientists criticized Galileo against his helicocentrism.　Some critics said that if the earth was moving a ball should not fall dawn vertically but show some deflection, as shown in the figure-a. Galileo offered a counterargument with a figure like Fig. b.　Explain.

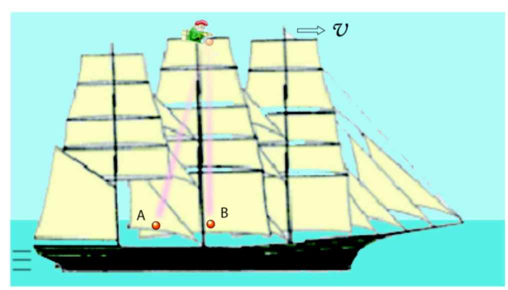
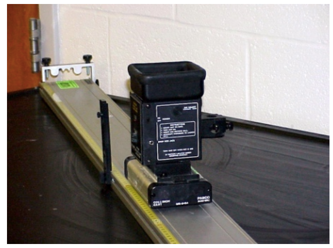



Fig. b

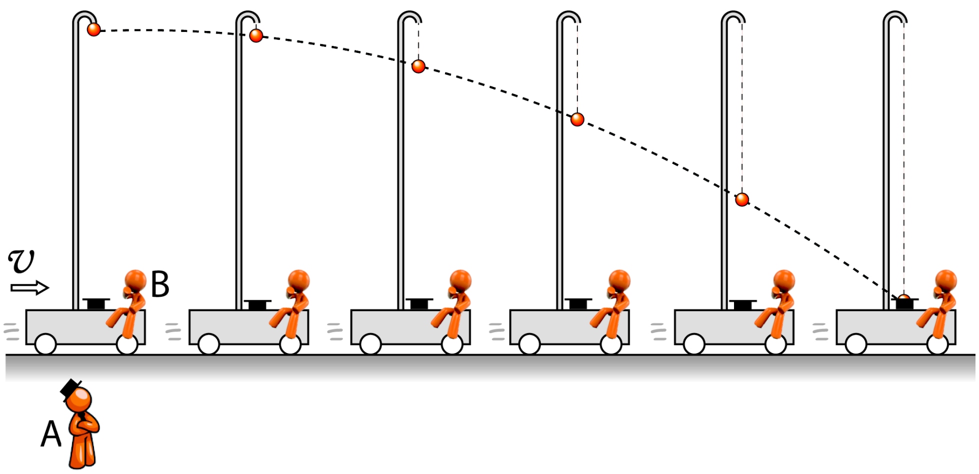
[Q23] Inside a Shinkansen train moving at a constant speed of 300 km/h or 83.3 m/s, a boy jumps and a girl drops a ball.
What happens?

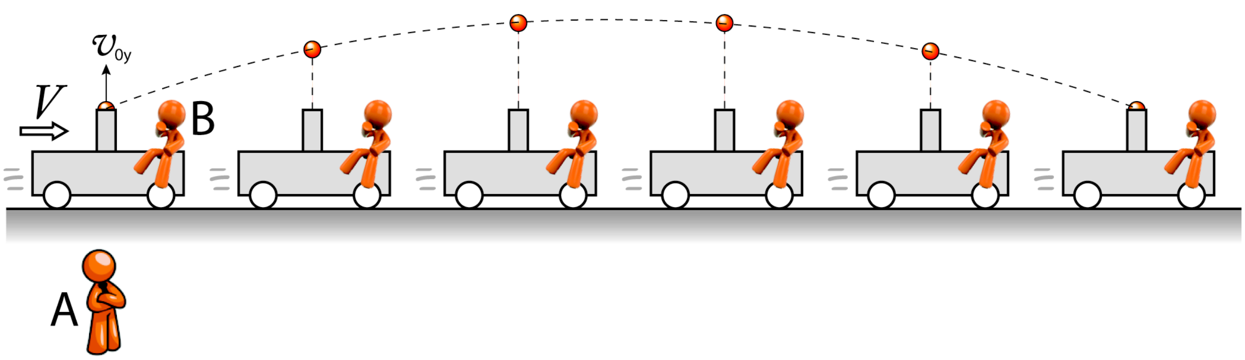
Fig. 23

[Mini-Lab 33] Ballistic Cart (PASCO)



The figures below show demonstrations in class. Explain the motion of a falling ball from two people's standpoints of view.

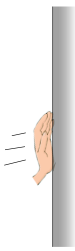


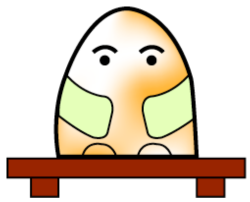
## 2. Newton's Third Law of Motion (The Law of Action and Reaction )

[Q41] Newton's third law of motion: "Nature never produces just one force at a time; *forces always come in pairs simultaneously*. In addition, the forces in a pair, which always act on *different objects*, are equal in magnitude and opposite in direction."
Translate the above law into Japanese.

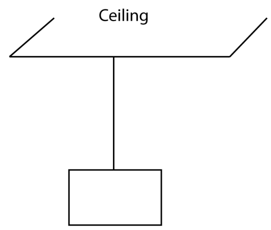
[Q42] Draw force vectors in the following figures and explain about the relations of action and reaction.



a) Pushing a wall

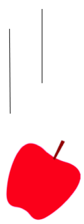


b) Kokeshi on a desk



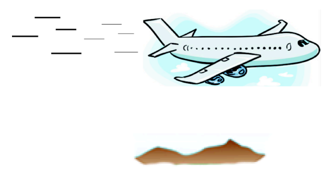

c) Suspended from a ceiling

d) Sumo

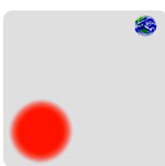


e) A falling apple

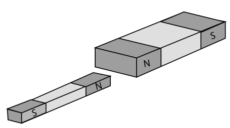
f) Moving car



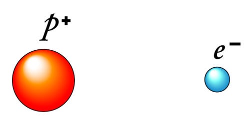
g) Flying airplane



h) The Sun and the earth

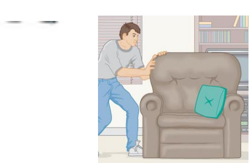


i) Strong and weak magnets




j) Proton and electron

k) A lady on a scale

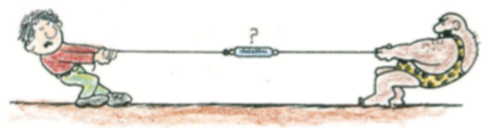


l) Pushing a sofa

m) A swimming ring

[Q43-a] When you and Sam Strongman each exert equal and opposite 500-N, the scale reading is:

A. 0 N. B. 500 N. C. 1000 N D. None of these.

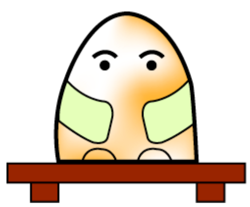


[Q43-b] The person to win the tug of war is the one who

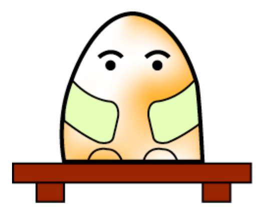
E. pulls harder on the rope than the other.
F. exerts a yanking force.
G. Both of these.
H. None of these.

[Q43-c] What force is responsible for victory in tug of war?

[Q44] In the following two figures, draw force vectors.

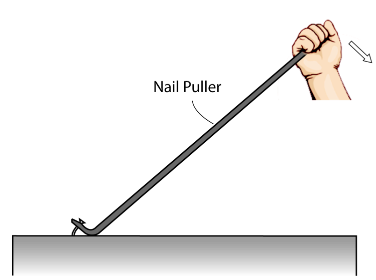


(a) Two forces in equilibrium



(b) Two forces in the relation of action-reaction

[Q45] A nail on wood board is pulled with a nail puller. Draw force vectors in the following figures and explain about the relations of action and reaction.



[Q46] Three identical springs are used in the following three ways. Which spring shows the largest elongation and which shows smallest?

[Mini-Lab 34]

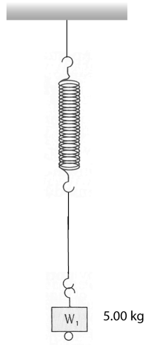



Fig. 38-a

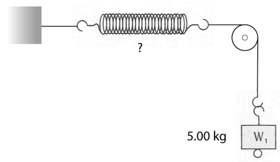



Fig. 38-b

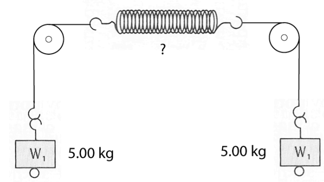
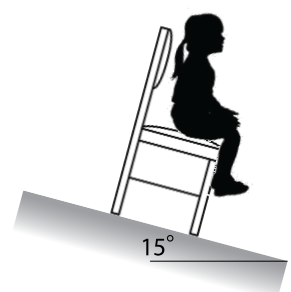



Fig. 38-c

[Q46] A 9.5-kg child sits at rest in a 3.7-kg chair that is also at rest on a slope inclined at an angle of 15° with the horizontal, as shown in the figure.




(1) Draw a free-body diagram for the child, and find the magnitude of the normal force exerted on the child.
(2) Draw a free-body diagram for the chair, and find the magnitude of the normal force exerted by the slope on the chair.

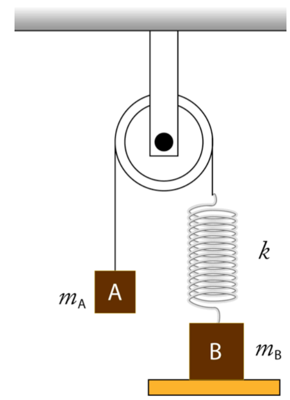
(1) Answer Draw a free-body diagram for the child.

Normal Force:

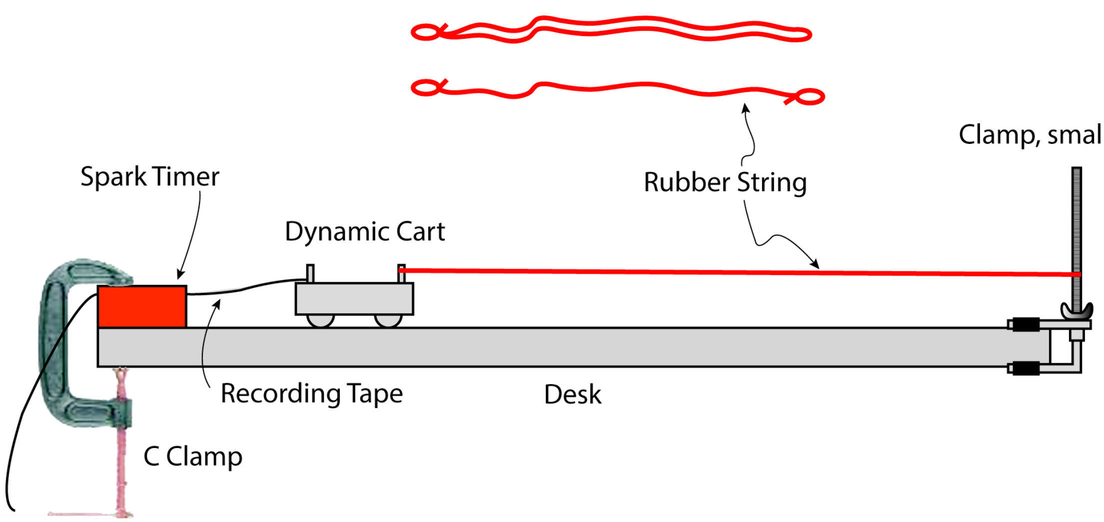
(2) Answer Draw a free-body diagram for the chair.

Normal Force:

[Q46] Two blocks, A and B, whose mass is $m_A$=0.50 kg and $m_B$=0.60 kg, are connected by a light string and a light spring having a spring constant k = 70 N/m.　The string passes over a light and frictionless pulley, and then the mass B is placed on a board, as shown in the figure.　(1) Find the tensional force pulling the mass A.　(2) Find the elongation of the spring.　(3) Find the normal force exerted by the board on the mass B.




[Mini-Lab 35]　Newton's Second Law



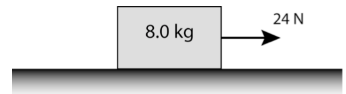
## 3. Newton's Second Law (The Law of Motion) (W p153~167)

The Equation of Motion

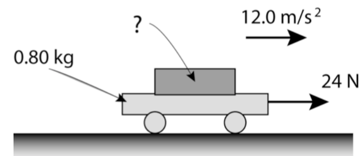
$$\Sigma \vec{F} = m\vec{a} \qquad (1)$$

If an object of mass $m$ is acted on by a net force $\Sigma \vec{F}$, it will experience an acceleration $\vec{a}$ that is equal to the net force divided by the mass. Because the net force is a vector, the acceleration is also a vector. In fact, the direction of an object's acceleration is the same as the direction of the net force acting on it.

[Q31] An 8.0 kg material on a frictionless surface is exerted by a force of 24 N. What is the magnitude of acceleration rate?




[Q32] A force of 24 N is acted on a 0.80 kg dynamic cart on a frictionless level surface, where a weight is placed on the cart. If an acceleration of 12.0 $m/s^2$ is produced, what is the mass of the weight?




[Q33] Forces are continuously acted on a 6.0 kg body on a frictionless surface, as shown. Find the direction and magnitude of acceleration rate.

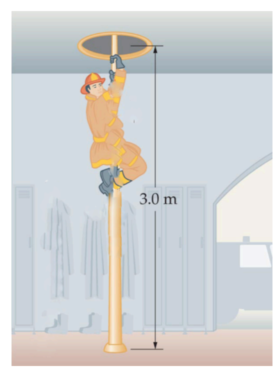

[Q34] According to the law of action-reaction, the force a sumo wrestler exerts on a kid is just the same in magnitude as the force the kid exerts on the sumo wrestler. Why does the sumo wrestler win?

[Q35] The metal head of hammer is loose. To tighten it, you drop the hammer down on to a table. Which way in the figure is more effective or do you get the same result either way?

## 4. Weight (P163)

[Q36] Explain why a person of mass m has a weight equal to mg.

[Q37] (a) The fire alarm goes off, and 97 kg fierfighter slides down a pole with a constant acceleration of a = $4.2/s^2$. What is the upward force exerted by the pole on the firefighter?
(b) What is the firefighter's acceleration if the force exerted on him by the pole is 650 N?



## 5. Motion of an Object under Forces in Equilibrium

| Forces in Equilibrium | |
|---|---|
| $\Sigma \vec{F} = 0 \rightarrow \vec{a} = 0$ | (2) |

[Q16] A 2.5 kg dynamic cart is moving on a frictionless horizontal surface at a constant velocity of 1.0 m/s.

(a) Draw all the forces acting on this cart.

(b) Show the equation of motion in terms of vector components.

(c) Find the acceleration rates, velocities and displacements of the cart in terms vector components as functions of time.

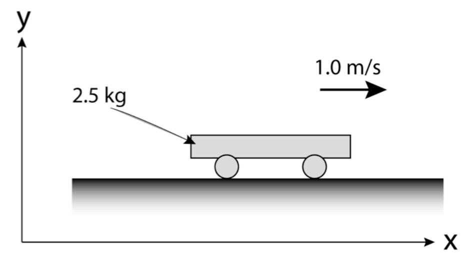



Fig. 16

## 6. Free Falling Motion

[Q18] Newton is watching an apple of a mass $m$ falling.

(a) Draw all the forces acting on the apple.

(b) Show the equation of motion in terms of vector components.

(c) Find the acceleration rates, velocities and displacements of the apple in terms vector components as functions of time.


Fig. 18

## 7. Projectile Motion – Zero Launch Angle

| | | | |
|---|---|---|---|
| $v_x = v_{ox}$, | $x = v_{0x}t$ | (5) | |
| $v_y = gt$, | $y = \frac{1}{2}gt^2$ | (6) | Downward: positive |

[Q21] A bullet is fired horizontally from a height of $h$ [m] at a speed of $v_0$ [m/s].

(a) Draw all the forces acting on the bullet.

(b) Show the equation of motion in terms of vector components.

(c) Find the acceleration rates, velocities and displacements of the bullet in terms vector components as functions of time.

(d) How far does it travel before it hit the ground assuming $h$ =33.8 m and $v_0$ = 400 m/s ($4.00 \times 10^2$ m/s).

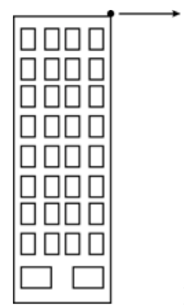


Fig.21

# 8.　Projectile Motion – General Launch Angle

| | | | |
|---|---|---|---|
| Projectile Motion　放物運動　（斜方投射） | | | |
| $v_x = v_{ox}$, | $x = v_{0x}t$ | (5) | |
| $v_y = v_{oy} - gt$, | $y = v_{0y}t - \frac{1}{2}gt^2$ | (6) | Upward: positive |

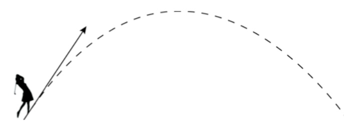
[Q23] A golfer tees off on level ground, giving the ball an initial speed of $v_0$ [m/s] and an initial direction of $\theta$ [°]above the horizontal.

(a) Draw all the forces acting on the ball.

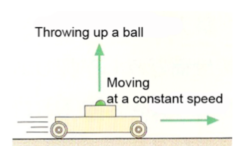
(b) Show the equation of motion in terms of vector components.

(c) Find the acceleration rates, velocities and displacements of the ball in terms vector components as functions of time.

(d) How far does it travel before it hit the ground assuming $v_0$ = 52.7 m/s and $\theta$ =42.5.



[Q24] When a dynamic cart is moving on level ground at a constant speed, a ball is thrown up from the cart. What motion do you observe about the ball?



## 9. Forces in Two Dimensions (W p161~162)

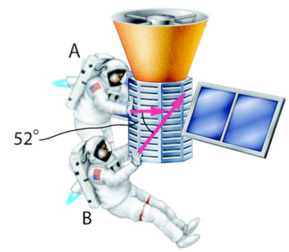


Fig. a

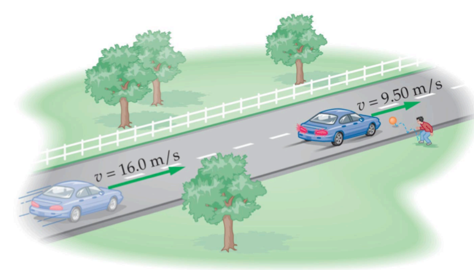
[Q25] Two astronauts are using jet packs to push 940 kg satellite toward the space shuttle, as shown in Fig. a. Astronaut A pushes with a force of magnitude 26 N and astronaut B pushes with a force of magnitude 41 N.


Fig. b

[Q25-1] Draw a "free-body diagram" in Fig. b using a point mass and arrows representing forces acting on it.

[Q25-2] Choose a convenient coordinate system and then apply Newton's second law to each coordinate direction, and then find the direction and magnitude of the acceleration generated on the point mass.

[Q25-3] Find the direction and magnitude of the acceleration using another method, from the net force.




[Q27] During home from school one day, you spot a ball rolling out into the street as shown in the figure. 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?

## 10. Static Friction (W p.170~176)

| | | |
|---|---|---|
| Static friction | $0 \le f \le F_0$ | |
| Maximum Limit of Static Friction | $F_0 = \mu N$ | (7) |
| Friction Angle, $\theta_0$ | $\mu = \tan\theta_0$ | (8) |

[Q31] In Fig. 31, an object is pulled by the spring scale at a force of $\vec{f}$ but does not move. Explain why.

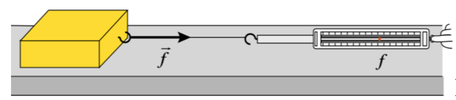
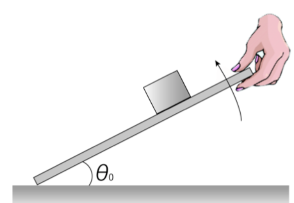


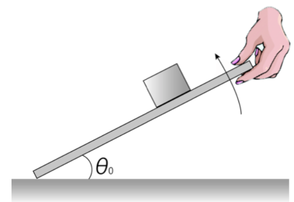
Fig. 31

[Q32] It takes a force of 35 N to start a 5.0 kg wooden block. Find the coefficient of static friction.

[Q33] An object of a mass 1.0 kg is placed on a flat and level desk. What is the minimum horizontal force to move the object assuming the coefficient of static friction between the desk and the object is 0.5.

[Q34] An object of a mass $m$ is placed on a flat board. The board is tilted upward. For small angles of tilt the object stays put, but when the tilt angle exceeds $\theta_0$, the object begins to slides. Find the coefficient of static friction between the board and the object.






[Q34-1] A 97 kg sprinter wishes to accelerate from rest to a speed of 13 m/s in a distance of 22 m.　What coefficient of static friction is required between the sprinter's shoes and the track?

[Q34-2] A 48 kg crate is placed on an inclined ramp.　When the angle the ramp makes with the horizontal is increased to 26°, the crate begins to slide downward.　(a) What is the coefficient of static friction between the crate and the ramp?　(b) At what angle does the crate begin to slide if its mass is doubled?

[Mini-Lab 36, Lab]　Friction

## 11. Kinetic Friction

| | | |
|---|---|---|
| Force of Kinetic Friction | $F' = \mu' N$ | (9) |

[Q35] Table 35 indicates typical coefficients of static and kinetic friction. In our lives, when is it desirable to reduce friction and when do we want as much friction as possible?

Table 35 Typical Coefficients of Friction

| Materials | | Static $\mu$ | Kinetic $\mu'$ |
|---|---|---|---|
| Rubber | Concrete(dry) | 1 – 4 | 0.80 |
| Steel | Steel | 0.74 | 0.57 |
| Glass | Glass | 0.94 | 0.40 |
| Wood | Leather | 0.50 | 0.40 |
| Copper | Steel | 0.53 | 0.36 |
| Rubber | Concrete(wet) | 0.30 | 0.25 |
| Steel | Ice | 0.10 | 0.06 |
| Waxed ski | Snow | 0.10 | 0.05 |
| Teflon | Teflon | 0.04 | 0.04 |
| Synovial joint in humans | | 0.01 | 0.003 |

[Q36] A car drives with its tires rolling freely. Is the friction between the tires and the road kinetic or static?

[Q37] When you push a 1.80 kg book resting on a tabletop, it takes 2.25 N to start the book sliding. Once it is sliding, however, it takes only 1.50 N to keep the book moving with constant speed. What are the coefficient of static and kinetic friction between the book and the tabletop?

[Q38] A baseball player slides into third base with an initial speed of 4.0 m/s. If the coefficient of kinetic friction between the player and the ground is 0.46, how far does the player slide before coming rest?

[Q39] Someone at the other end of the table asks you to pass the salt. Feeling quite dashing, you slide the 50.0-g salt shaker in their direction, giving it an initial speed of 1.15 m/s.

(a) If the shaker comes to rest with constant acceleration in 0.840 m, what is the coefficient of kinetic friction between the shaker and the table?

(b) (b) How much time is required for the shaker to come to rest if you slide it with an initial speed of 1.32 m/s?

## 12. Advanced Problems using the Equation of Motion

＊Sea lion problems

[Q40] A trained sea lion slides from rest with constant acceleration down a 3.0-m-long ramp into a pool of water. The ramp is inclined at an angle of 23° above the horizontal and the coefficient of kinetic friction between the sea lion and the ramp is 0.26.

a) Draw a free-body diagram.
b) Find the acceleration rate of the sea lion.
c) How long does it take for the sea lion to make a splash in the pool?
d) Find the velocity of the sea lion when it reaches the water.

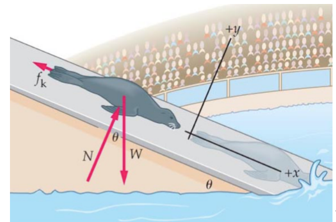


Fig. 40

*[Q41] When an object is place on a inclined surface at an angle of $\theta$, it slides down from rest at a constant acceleration rate $a$. Assume that the coefficient of kinetic friction between the object and the inclined surface is $\mu'$ and the gravitational acceleration rate is $g$.

a) Draw a free-body diagram.
b) Find the acceleration rate $a$.
c) Find the time the object slides in the distance $L$.
d) Find the velocity $v$ when the object slides in a distance $L$.

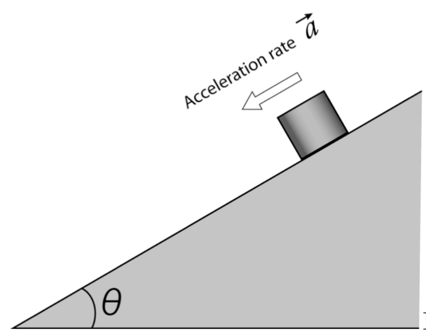


Fig. 41

## ＊Elevator problems – Apparent Weight

[Q42] Find the magnitude of the tensional force of the string in the figure in the following conditions:

a) At rest.
b) Moving downward at a constant speed of 1.5 m/s.
c) Moving upward at a constant acceleration rate of 1.2 $m/s^2$ upward.
d) Moving downward at a constant acceleration rate of 1.2 $m/s^2$ downward.

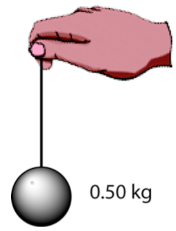


Fig. 42

[Q43] A 71-kg woman is standing on a scale in an elevator. What is the apparent weight by kg as indicated by the scale in the following conditions?

e) The elevator is at rest.
f) Moving downward at a constant speed of 1.5 m/s.
g) Moving upward at a constant acceleration rate of 3.0 $m/s^2$ downward.
h) Moving downward at a constant acceleration rate of 3.0 $m/s^2$ upward.


Fig. 43

## * Contact forces

[Q44] A box of mass 2.30 kg rest on a smooth, horizontal floor next to a box of mass 4.20 kg. You push on the 2.30 kg box with a horizontal force of magnitude 8.50 N.

a) What is the acceleration of the boxes?
b) What is the force of contact between the boxes?

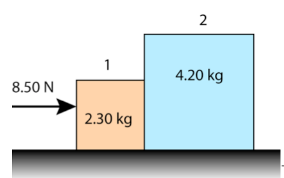


Fig. 44

[Q45] In the above, you push on the 4.20 kg box with a horizontal force of magnitude 8.50 N.

a) What is the acceleration of the boxes?
b) What is the force of contact between the boxes?

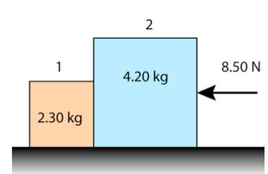


Fig. 45

*[Q46] A force of magnitude 8.50 N pushes three boxes with masses $m_1$ = 2.30 kg, $m_2$ = 4.20 kg and $m_3$ = 5.90 kg as shown.

a) Find the magnitude of the contact force between boxes 1 and 2.

b) Find the magnitude of the contact force between boxes 2 and 3.

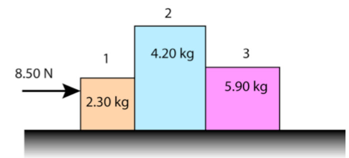



Fig. 46

[Q47] A tugboat is pulling three cargoes of the same mass connected with rope and moving at constant acceleration. The tensional force of the first rope is $3.0 \times 10^3$ N. Find the tensional forces of the other ropes assuming the resistances acting on the three cargoes are the same.

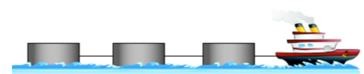


Fig. 47

* Atwood machine

[Q48] Atwood's machine consists of two masses connected by a string that passes over a pulley, as shown by the figure.

a) Find the acceleration of the masses for general $m_1$ and $m_2$, and the tensional force of the string.

b) Evaluate for the specific case $m_1$ = 3.1 kg, $m_2$ = 4.4 kg.

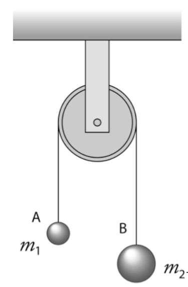



Fig. 48

[Q49] A block of mass $M$ is on a tabletop. It is connected to a string that passes over a pulley and suspends a mass $m$. The coefficient of kinetic friction between the desk and the block is $\mu'$.

a) Find the acceleration of the blocks.

b) Find the tension in the string.

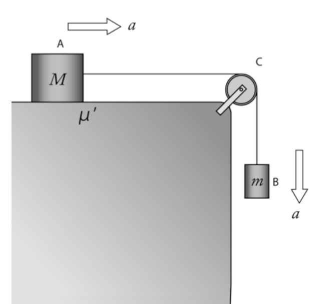
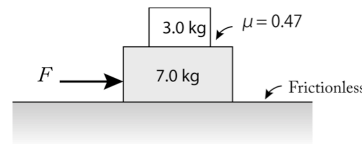
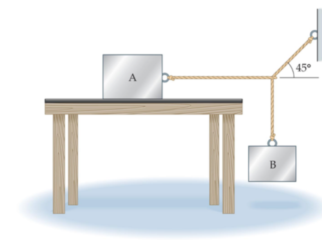



Fig. 49

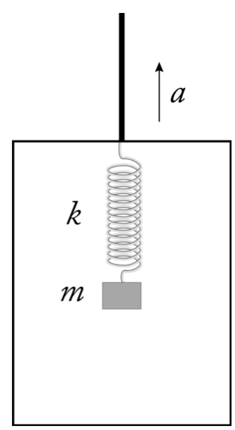
[Q50] Two blocks, stacked one on top of the other, can move without friction on the horizontal surface shown in the figure. The surface between the two blocks is rough, however, with a coefficient of static friction equal to 0.47. If a horizontal force $F$ is applied to the 7.0 kg bottom block, what is the maximum value $F$ can have before the 3.0 kg top block begins to slip?




[Q51] The blocks shown in the figure are at rest. (a) Find the frictional force exerted on block A given that the mass of block A is 8.82 kg, the mass of block B is 2.33 kg, and that the coefficient of static friction between block A and the surface on which it rests is 0.320.
(b) What is the maximum mass block B can have and the system still be in equilibrium?




[Q52] A 1.5 kg weight hangs from a spring with a spring constant of 77 N/m supported from the roof of an elevator. If the elevator has an upward acceleration of 2.5 m/s$^2$, how and how much does the spring change in length in reference to the elevator at rest?



# 13. Free Falling Motion in Viscous Medium

**Falling in a Viscous Medium （Resistance in case of a spherical body $f = -kv$)**

**Terminal Velocity**　　$v_{terminal} = \frac{mg}{k}$　　(5)

[Q60] Which falls faster, an elephant or a man if the resistance by air can be ignored? Fig. 40 is Galileo's thought experiment. Explain.

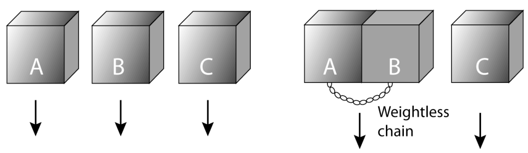
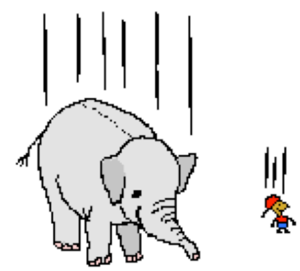


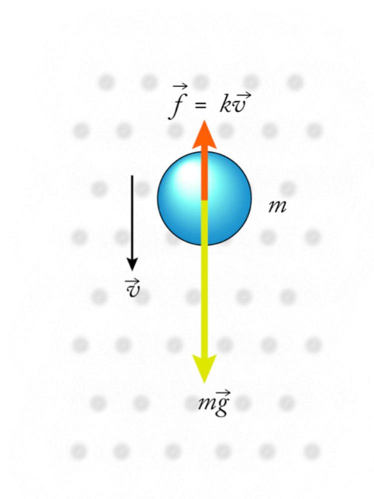
Fig. 40



[Q61] Which falls faster, an elephant or a man if the resistance by air cannot be ignored? What factors affect the result? Draw a graph how the velocity changes with time.

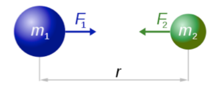
[Q42] Terminal Velocity

| Falling Object (radius) | Mass kg | Area $m^2$ | Terminal Velocity m/s | km/h |
|---|---|---|---|---|
| Skydiver | 75 | 0.7 | 60 | 214 |
| Baseball (3.66 cm) | 145 x$10^{-3}$ | 42 x $10^{-4}$ | 33 | 118 |
| Golf ball (2.1 cm) | 46 x$10^{-3}$ | 14 x $10^{-4}$ | 32 | 115 |
| Hail stone (0.5 cm) | 48 x$10^{-3}$ | 0.79 x $10^{-4}$ | 14 | 50 |
| Raindrop (0.2 cm) | 34 x$10^{-6}$ | 0.13 x $10^{-4}$ | 9 | 32 |



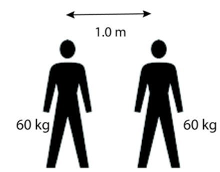

[Q63] A rain drop of 4.5 x $10^{-8}$ kg is falling at 0.80 m/s. Supposing that the magnitude of resistance by air is proportional to the speed of the rain drop $v$ and then expressed as $kv$ ( $k$ is a proportional constant) find the magnitude of air resistance. Also find the value of $k$.

# 14. The Law of Universal Gravitation (W p307)

| | | |
|---|---|---|
| Law of Universal Gravitation | $F_1 = F_2 = G\frac{m_1 \cdot m_2}{r^2}$ (2)<br>(G = 6.67 x $10^{-11}$ $Nm^2/kg^2$) |  |



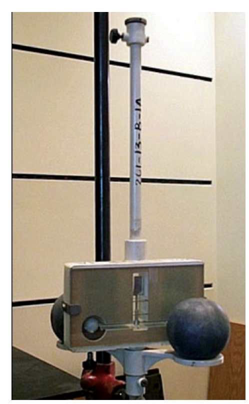
[Q9] Find the attractive force acting on two people that stand 1.0 m apart.




[Q10] Using the Law of Universal Gravitation find the gravitational force, *W*, acting on an apple of a mass *m* that is close to the surface of the earth.

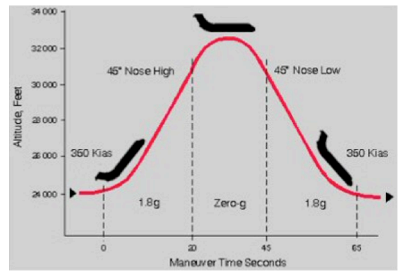
| | |
|---|---|
| The radius of the Earth | Approximately 6,400 km |
| The mass of the Earth | 5.97 x $10^{24}$ kg |

[Mini-Lab #21] Cavendish Experiment

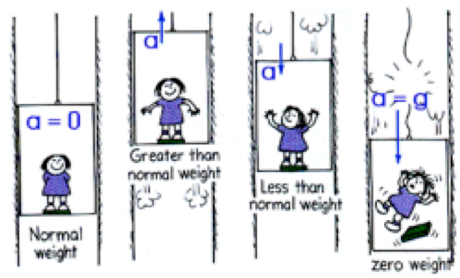


[Q11] It is often said that astronauts in orbit experience “zero gravity” or weightlessness because they are beyond the pull of Earth’s gravity. Is this statement correct? Explain.

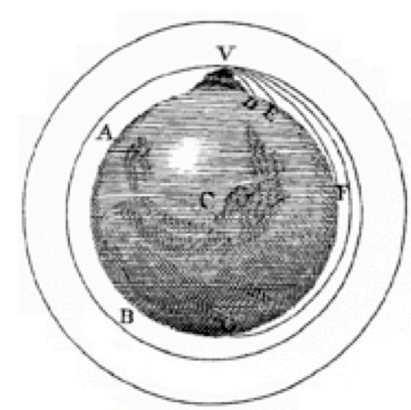
(a)




(b)




(c)




(d)

[Mini-Lab #22] Weightlessness

| | |
|---|---|
| 1. Force | 力 |
| Point of Action | 作用点 |
| Vector | ベクトル |
| Gravity | 重力 |
| Newton [N] | ニュートン [N] |
| Mass | 質量 |
| Newton's Law of Universal Gravitation | ニュートンの万有引力の法則 |
| Elasticity | 弾性 |
| Elestic Force | 弾性力 |
| Hooke's Law | フックの法則 |
| Spring Constant | ばね定数 |
| Equilibrium | つりあい |
| Resistance | 抗力 |
| Normal Force | 垂直抗力 |
| Tension | 張力 |
| Buoyancy | 浮力 |
| Archimedes' Principle | アルキメデスの原理 |
| "Eureka!" /jʊˈriːkə/ | 「ユリーカ！」見つけた！ |
| Density | 密度 |
| Electrical Force | 電気の力 |
| Magnetic force | 磁気の力 |
| Friction | 摩擦力 |
| 2. Pressure | 圧力 |
| Atmospheric Pressure | 気圧 |
| Pascal [Pa] | パスカル [Pa] |
| Atmosphere [atm] | 気圧 [atm] |
| Hydrostatic Pressure | 水圧 |
| 3. Addition of Forces | 力の合成 |
| Resolution of Forces | 力の分解 |
| Free-body diagram | フリーボディダイアグラム |
| Net Force | 合力 |
| Component | 成分 |
| 4. Rigid Body | 剛体 |
| Torque | 力のモーメント |
| Couple | 偶力 |
| 5. Center of Gravity（COG） | 重心 |

| | |
|---|---|
| 1. The Law of Inertia | 慣性の法則 |
| (Newton's 1st Law of Motion) | (ニュートンの運動第１法則) |
| 2. The Law of Motion | 運動の法則 |
| (Newton's 2nd Law of Motion) | (ニュートンの運動第２法則) |
| 3. The Law of Action-Reaction | 作用・反作用の法則 |
| (Newton's 3rd Law of Motion) | (ニュートンの運動第３法則) |
| 4. Motion of an Object in Equilibrium | 力がつりあっているときの物体の運動 |
| 5. Free Fall and the Law of Motion | 自由落下運動と運動の法則 |
| 6. Projectile Motion and the Law of Motion | 放物運動と運動の法則 |
| 7. Friction | 摩擦 |
| Frictional Forces | 摩擦力 |
| Static Friction | 静止摩擦 |
| The Maximum Limit of Static Friction | 最大静止摩擦力 |
| Coefficient of Static Friction | 静止摩擦係数 |
| Angle of Friction | 摩擦角 |
| 8. Kinetic Friction | 動摩擦 |
| Force of Kinetic Friction | 動摩擦力 |
| Smooth Surface | なめらかな面（摩擦係数が０の面） |
| Rough Surface | 荒い面（摩擦がある面） |
| 9. Terminal Speed | 終端速度 |
| 10. Applications of Newton's Law | ニュートンの法則の応用 |
| Atwood Machine | アトウッドの器械 |