VP160 Recitation Class III

Zeyi Ren

UM-SJTU Joint Institute

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Force and Inertial Frame of Reference

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  e.g. gravitational force

Inertial frame of reference

In an inertial FoR, a physical object with zero net force acting on it moves with a constant velocity (which might be zero), or, equivalently, it is a frame of reference in which Newton's first law of motion holds.

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$$\vec{F} = m\vec{a}$$

Using Newton's second law, normally we can derive the equation of motion:

$$\frac{d^2 r}{dt^2} = \frac{F(\dot{r}, r, t)}{m}$$

with $v(t_0) = v_0, r(t_0) = r_0$ known, it's an initial value problem to be solved.

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The mutual forces of action and reaction between two bodies are equal in magnitude and opposite in direction.

$$\vec{F}_1 = -\vec{F}_2$$

Free-body diagram

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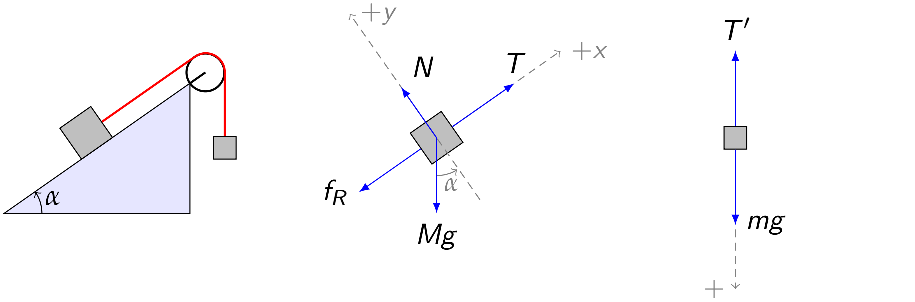
4. Weight


α
+y
N
T
+x
f_R
α
Mg
T′
mg
+

Background

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Exercise 1

Application of free-body diagram and "Isolation Method"

Two identical smooth balls A and B are suspended from a fixed point O by two ropes of the same length. The two balls also support a smooth ball C of the same weight with A and B, as shown in the Fig. The system are now at an equilibrium. **Find** the relationship between α and β.

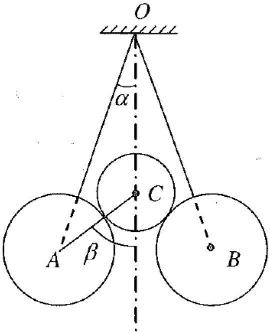


Figure 1. Exercise 1.

Exercise 2

Force of friction and "Whole Method"

Two blocks with mass m_1 and m_2 are stacked on the horizontal desk. Another block with mass m connected to m_1 and m_2 with an inextensible rope is put onto a pulley system. The system is showed in Fig.2. Suppose the friction coefficient between m_1 and m_2 is μ, and the desk is smooth enough to neglect friction. **Find:**

What conditions does the system need to satisfy if there is no relative sliding between m_1 and m_2.

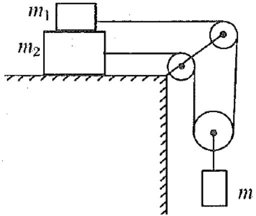


Figure 2. Exercise 2.

Exercise 3

Mass m hangs on a massless rope in a car moving with
(a) constant velocity $\mathbf{v}$,
(b) constant acceleration $\mathbf{a}$
on a horizontal surface. What is the angle the rope forms with the vertical direction.
Discuss the problems (a) (b) if the car slides (without friction) down a plane inclined at an angle α.

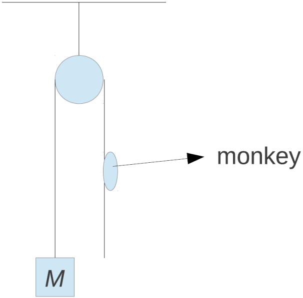
Exercise 4

A monkey with mass m holds a rope hanging over a frictionless pulley attached to mass M (see figure). Discuss motion of the system if the monkey

(a) does not move with respect to the rope,

(b) climbs up the rope with constant velocity $\mathbf{v_0}$ with respect to the rope,

(c) climbs up the rope with constant acceleration $\mathbf{a_0}$ with respect to the rope.



Exercise 5

Relative Motion and Newton's Second law

See in Fig.1, a split ABC with mass M, height h is placed on the horizontal plane. The inclination angle of AC is θ. A small object with mass m begin to slide down from A with initial velocity 0. Omitting the friction of each contact surface. **find**:

(a) The displacement of M when m reaches the ground,

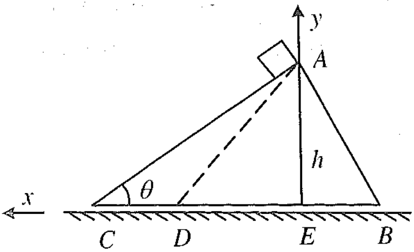
(b) in the ground FoR, the acceleration $\mathbf{a_1}$ of M.

(c) in the m FoR(small object), the acceleration $\mathbf{a_2'}$ of M,

(d) in the ground FoR, the acceleration $\mathbf{a_2}$ of m,

(e) the normal force N between m and M,

(f) the normal force R between M and the ground.



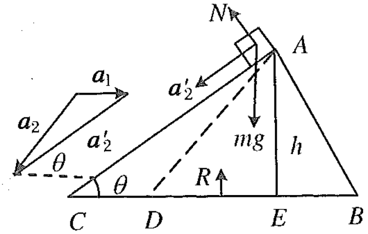


Figure 4. Exercise 5.

Motion with Air/Fluid Drag

Consider a particle with linear drag $\mathbf{F} = -k\mathbf{v}$ and initial velocity $\mathbf{v_0} = v_0 cos(\alpha)\hat{n_x} + v_0 sin(\alpha)\hat{n_y}$, what's its trajectory?

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What if quadratic drag force?

Reference

Yigao Fang.
VP160 Recitation Slides.
2020

Haoyang Zhang.
VP160 Recitation Slides.
2020

Jiafu Cheng (程稼夫).
中学奥林匹克竞赛物理教程：力学篇
University of Science and Technology Press, 2013