ALGEBRA-BASED PHYSICS-1: MECHANICS (PHYS135A-01): WEEK 5

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WEEK 4 REVIEW

1. Deep statements about physics: *dynamics* and *kinematics*
    - **Lab activity**: Force, mass and stretching springs
2. Newton's First Law
    - **Lab activity**: force tables
3. Newton's Second Law
4. Newton's Third Law
5. Applications
    - Free-body diagrams
    - Tension
    - Inclined surfaces
    - Restoring forces

WEEK 4 REVIEW PROBLEMS

A powerful motorcycle can produce an acceleration of 3.50 m/s^2 while traveling at 90.0 km/h. At that speed the forces resisting motion, including friction and air resistance, total 400 N. (Air resistance is analogous to air friction. It always opposes the motion of an object.) What is the magnitude of the force the motorcycle exerts backward on the ground to produce its acceleration if the mass of the motorcycle with rider is 245 kg?

- A: 1260 N
- B: 12,600 N
- C: 960 N
- D: 400 N

Two teams of nine members each engage in a tug of war. Each of the first team's members has an average mass of 68 kg and exerts an average force of 1350 N horizontally. Each of the second team's members has an average mass of 73 kg and exerts an average force of 1365 N horizontally. What is magnitude of the acceleration of the two teams? What is the tension in the section of rope between the teams?

- A: 0.106 m/s^2, 33435 N
- B: 0.106 m/s^2, 12150 N
- C: 0.955 m/s^2, 33435 N
- D: 0.955 m/s^2, 12150 N

WEEK 5 SUMMARY

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1. Friction
    - Normal force and friction
    - Static, kinetic
2. Drag
    - Terminal velocity
3. Restoring Forces
    - Hooke's Law
    - Young's modulus
    - Shear modulus
    - Bulk modulus

FRICTION

Some definitions:

- *Friction* is a force that opposes relative motion between systems in contact.
- *Kinetic friction* occurs between two systems that are in contact and moving relative to one another.
- *Static friction* is occuring between two systems in contact but there is no motion.

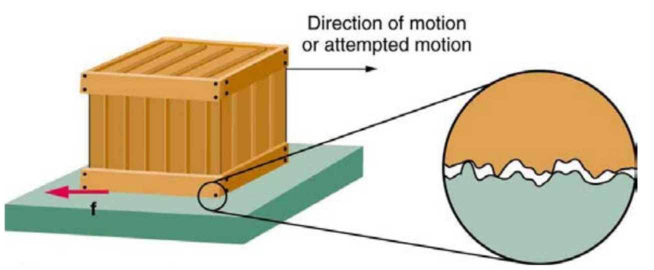

Figure 1: Friction is ultimately a microscopic phenomenon.

Let N be the normal force, and f is the force of friction opposing motion.

Static friction:

$$f_{\mathrm{s}} \leq \mu_{\mathrm{s}} N \tag{1}$$

Static friction maximum:

$$f_{\mathrm{s,max}} = \mu_{\mathrm{s}} N \tag{2}$$

Kinetic friction:

$$\boxed{f_{\mathrm{k}} = \mu_{\mathrm{k}} N \quad (\mu_{\mathrm{k}} < \mu_{\mathrm{s}})} \tag{3}$$

Table 5.1 Coefficients of Static and Kinetic Friction

System	Static friction μ_s	Kinetic friction μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.7	0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.4	0.02

Figure 2: A handy table of friction coefficients. For example, compare ice and concrete.

Suppose an object is moving horizontally along a surface, experiencing gravity and a normal force but no other forces. From Newton's second law, we have

$$\vec{F}_{\mathrm{net}} = m\vec{a} \tag{4}$$

$$\vec{f}_{\mathrm{f}} = -m\vec{a} \tag{5}$$

$$-f_{\mathrm{f}}/m = a \tag{6}$$

$$\mu_{\mathrm{k}} mg/m = a \tag{7}$$

$$a = \mu_{\mathrm{k}} g \tag{8}$$

We may think of the friction coefficient as the fraction of gravitational acceleration transduced into opposing motion.

What is the maximum frictional force in the knee joint of a person who supports 66.0 kg of her mass on that knee? During strenuous exercise it is possible to exert forces to the joints that are easily ten times greater than the weight being supported. What is the maximum force of friction under such conditions?

- A: 1.06 N, 1.06 N
- B: 0.157 N, 1.57 N
- C: 103 N, 1133 N
- D: 10.3 N, 113 N

Show that the acceleration of any object down a frictionless incline that makes an angle θ with the horizontal is $a = g \sin \theta$. (Note that this is independent of mass).

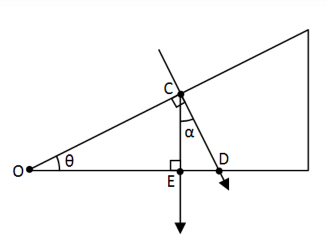

Figure 3: Example of an incline with angle θ with respect to horizontal.

Next, show that the acceleration of any object down the same incline that has kinetic friction coefficient μ_k is given by $a = g(\sin\theta - \mu_\mathrm{k}\cos\theta)$. Notice if we take the limit $\mu_\mathrm{k} \to 0$, we get the previous expression.

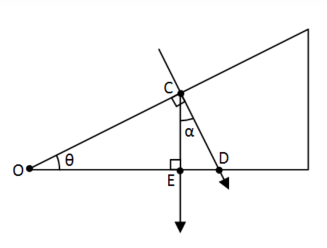

Figure 4: Now with friction!

A skiier is racing down a run with a 45 degree incline, and $\mu_{\mathrm{k}} = 0.1$. Assuming the initial speed is 10 m/s, how long does it take to reach 40 m/s? (Let $g = 10$ m/s^2).

- A: $3\sqrt{2}$ seconds
- B: $10\sqrt{2}/3$ seconds
- C: 10 seconds
- D: 30 seconds

DRAG

The force of drag resisting the motion of an object of cross-sectional area A moving at velocity v through a fluid with density ρ is

$$\boxed{F_{\mathrm{D}} = \frac{1}{2} C \rho A v^2} \tag{9}$$

In Eq. 9, C is a measured coefficient.

A professor is riding his bicycle to work, at a constant velocity of 10 m/s. His cross-sectional area is 1.0 m^2, the density of air is $\rho = 1.2$ kg/m^3, and $C \approx 0.5$. What is the force of drag? If he ducks down, making his area 0.25 m^2, what is the new force of drag?

- A: 30 N, 7.5 N
- B: 15 N, 15 N
- C: 30 N, 30 N
- D: 3 N, 3/4 N

Suppose an object is falling through the atmosphere of Earth. At a certain speed, the object stops accelerating. Why? The force of *drag balances the force of gravity*. Draw a free-body diagram describing the situation. If m is the mass of the falling object, g is the acceleration of gravity, C is the drag coefficient from Eq. 9, ρ is the density of air, and A is the area of the object, show that the maximum speed reached is $v_{\mathrm{T}} = \left(\frac{2mg}{C\rho A}\right)^{1/2}$. What is the terminal velocity of a skydiver with: $m = 64$ kg, $A = 0.5$ m^2, $g = 10$ m/s^2, $C \approx 1$, $\rho \approx 1$ kg/m^3?

- A: 1800 km/hr
- B: 180 km/hr
- C: 18 km/hr
- D: 80 m/s

Stoke's Law describes drag on small systems moving slowly through viscous media: $F_{\mathrm{D}} = 6\pi r \eta v$, where r is the radius of the object, v is the velocity, and η is the *viscosity* (kg/(s·m)). In the same fashion as the prior exercise, show that the terminal velocity is $v_{\mathrm{T}} = mg/6\pi\eta v$. Calculate this velocity assuming: $m \approx 10^{-9}$ kg, $r \approx 2 \cdot 10^{-3}$ m, $g \approx 10$ m/s^2, and $\eta \approx 2 \cdot 10^{-5}$ kg/(s m) for air.

- A: 100 cm/s
- B: 10 cm/s
- C: 1 cm/s
- D: 1 mm/s

RESTORING FORCES

Let F_{app} be an applied force on a system, causing the length of the system to change by $\vec{x}$. By Newton's Third Law, the system will exert a force F in reaction.

Hooke's Law

$$\vec{F} = -k\vec{x}$$

Hooke's Law is an example of a *restoring force*. Examples of systems that obey Hooke's Law are springs, pendula, and other oscillators.

If a system follows Hooke's Law and Newton's Second Law in one-dimension, then

$$m\frac{d^2x}{dt^2} = -kx(t) \tag{10}$$

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x(t) \tag{11}$$

What set of functions obeys this differential equation? Sines and cosines...

$$\vec{F} = -k\vec{x}$$

CONCLUSION

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- 10.3 N, 113 N
- $10\sqrt{2}/3$ seconds
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- 1 cm/s

- ...