

Chapter 12

Linear Kinematics of Human Movement

Basic Biomechanics, 4th edition

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Objectives

- Identify Newton's laws of motion and gravitation and describe practical illustrations of the laws
- Explain what factors affect friction and discuss the role of friction in daily activities and sports
- Define impulse and momentum and explain the relationship between them
- Explain what factors govern the outcome of a collision between two bodies
- Discuss the interrelationship among mechanical work, power, and energy
- Solve quantitative problems related to kinetic concepts

Newton's Laws

Law of Inertia

- A body will maintain a state of rest or constant velocity unless acted on by an external force that changes the state

Newton's Laws

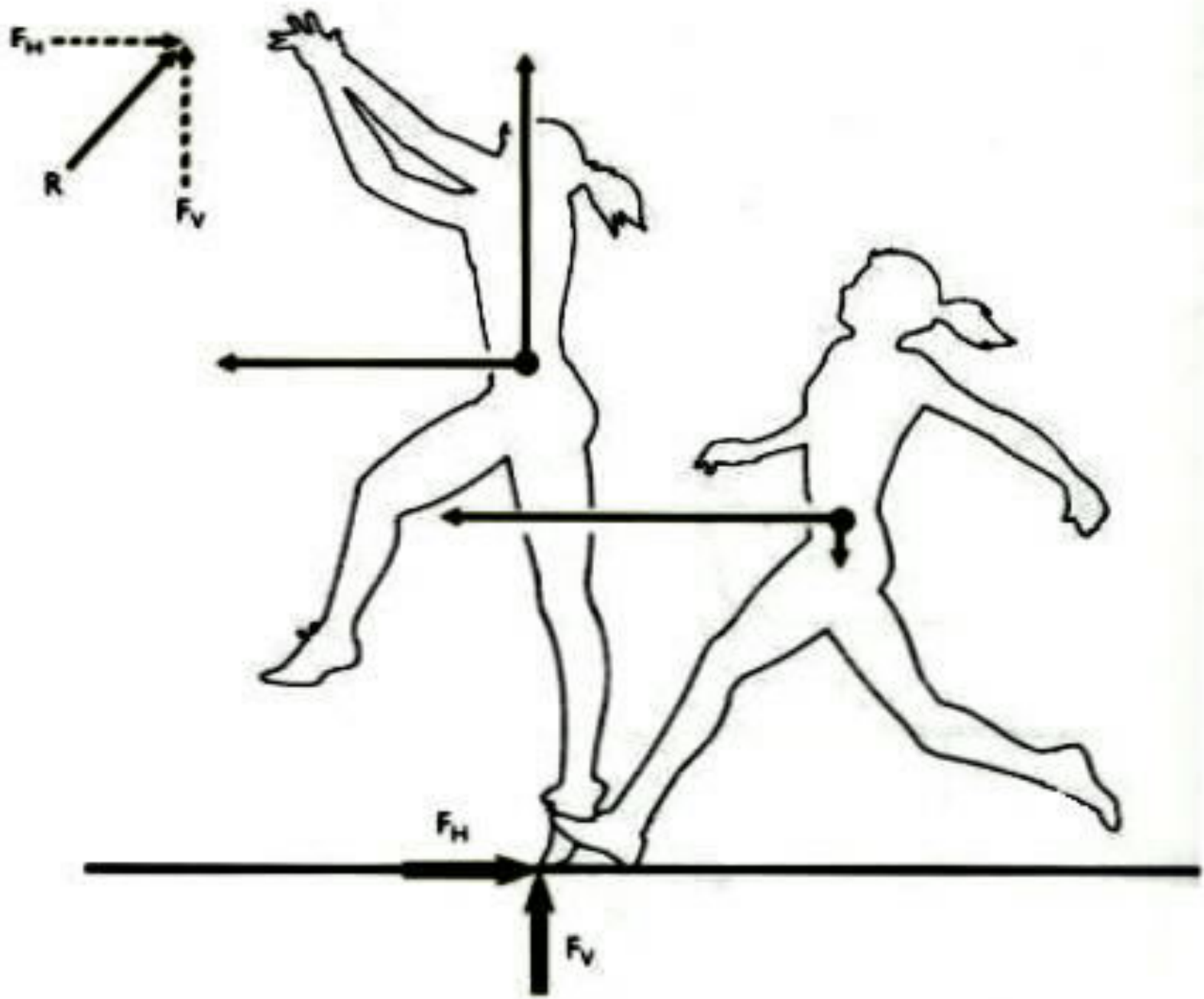
Law of Acceleration

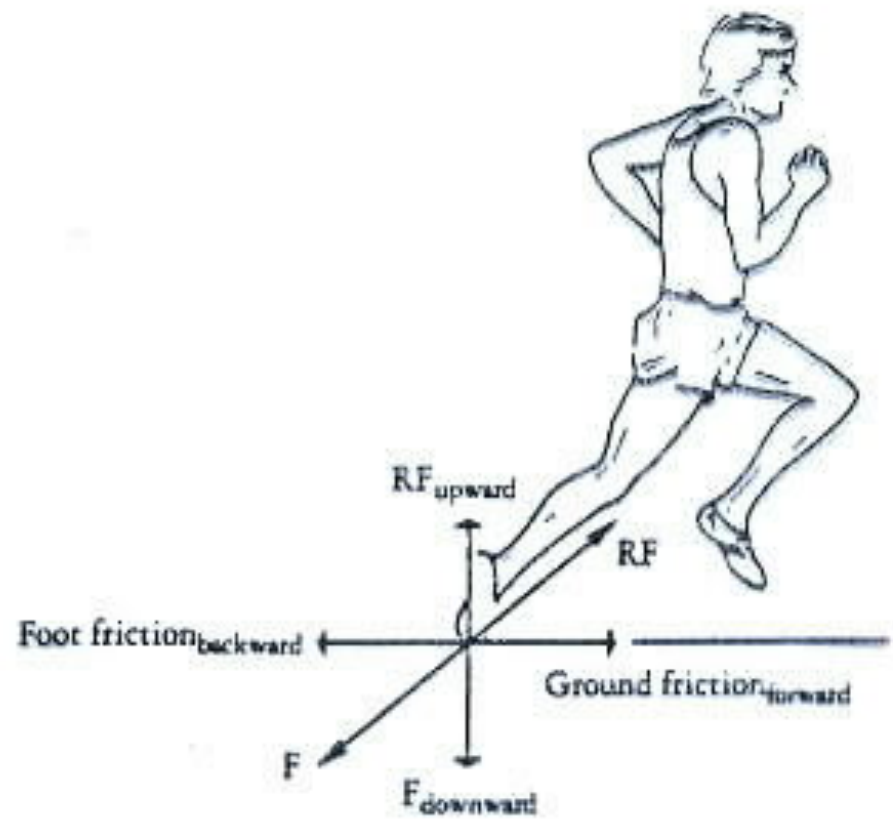
- A force applied to a body causes an acceleration of that body of a magnitude proportional to the force, in the direction of the force, and inversely proportional to the body's mass
- $F = ma$

Newton's Laws

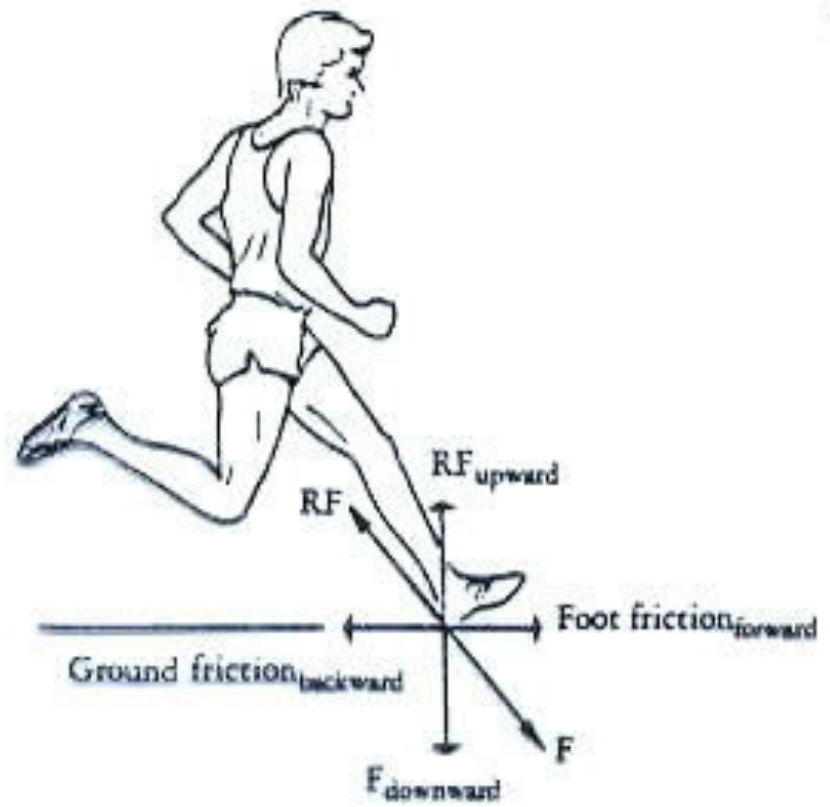
Law of Reaction

- For every action, there is an equal and opposite reaction
- When one body exerts a force on a second, the second body exerts a reaction force that is equal in magnitude and opposite in direction of the first body

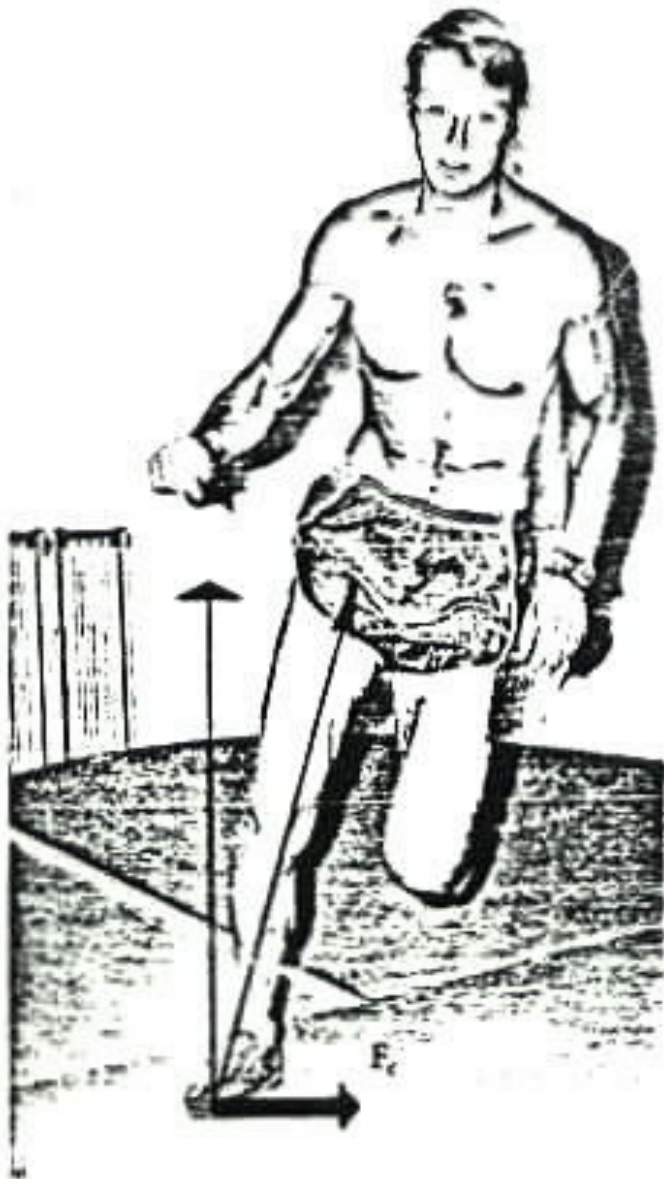




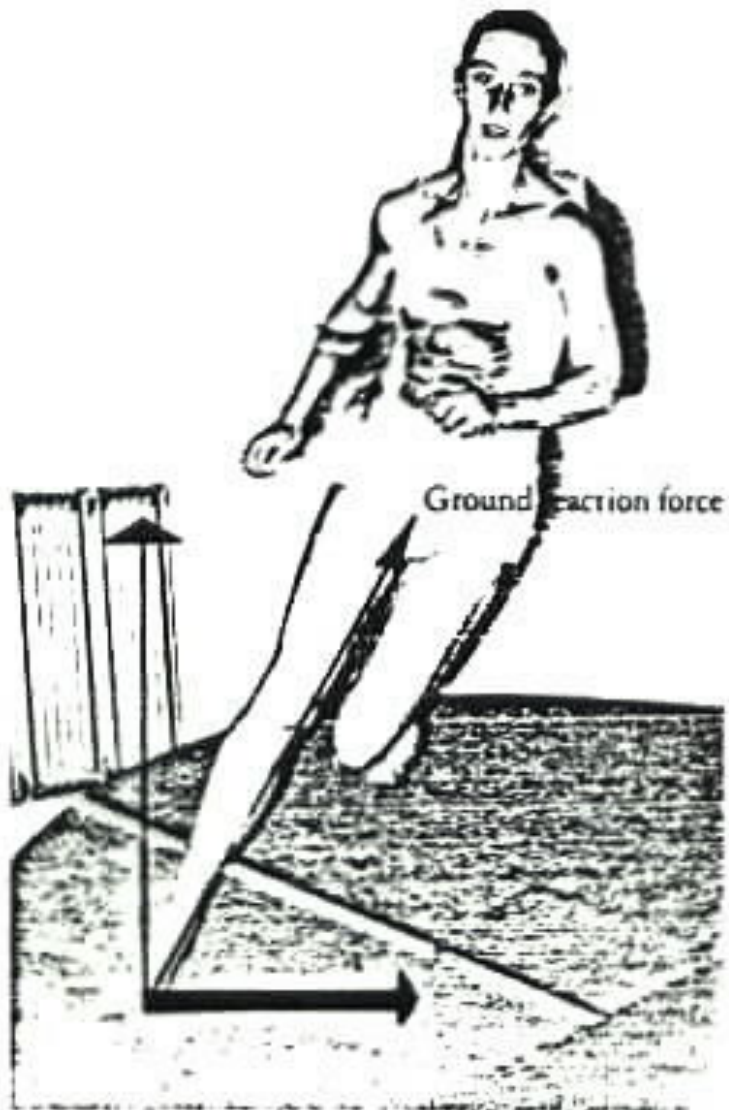
a Acceleration



b Deceleration



a Ground reaction centripetal force is more friction dependent on horizontal ground



b Ground reaction centripetal force is less friction dependent on banked surface

Newton's Laws

Law of Gravitation

- All bodies are attracted to one another with a force proportional to the product of the masses and inversely proportional to the square of the distance between them
- $F_g = G(m_1 m_2 / d^2)$

Mechanical Behavior of Bodies in Contact

Friction:

Maximum static friction (F_m):

Kinetic friction (F_k):

- $F = \mu R$

Coefficient of friction:

- Coefficient of static friction (μ_s):

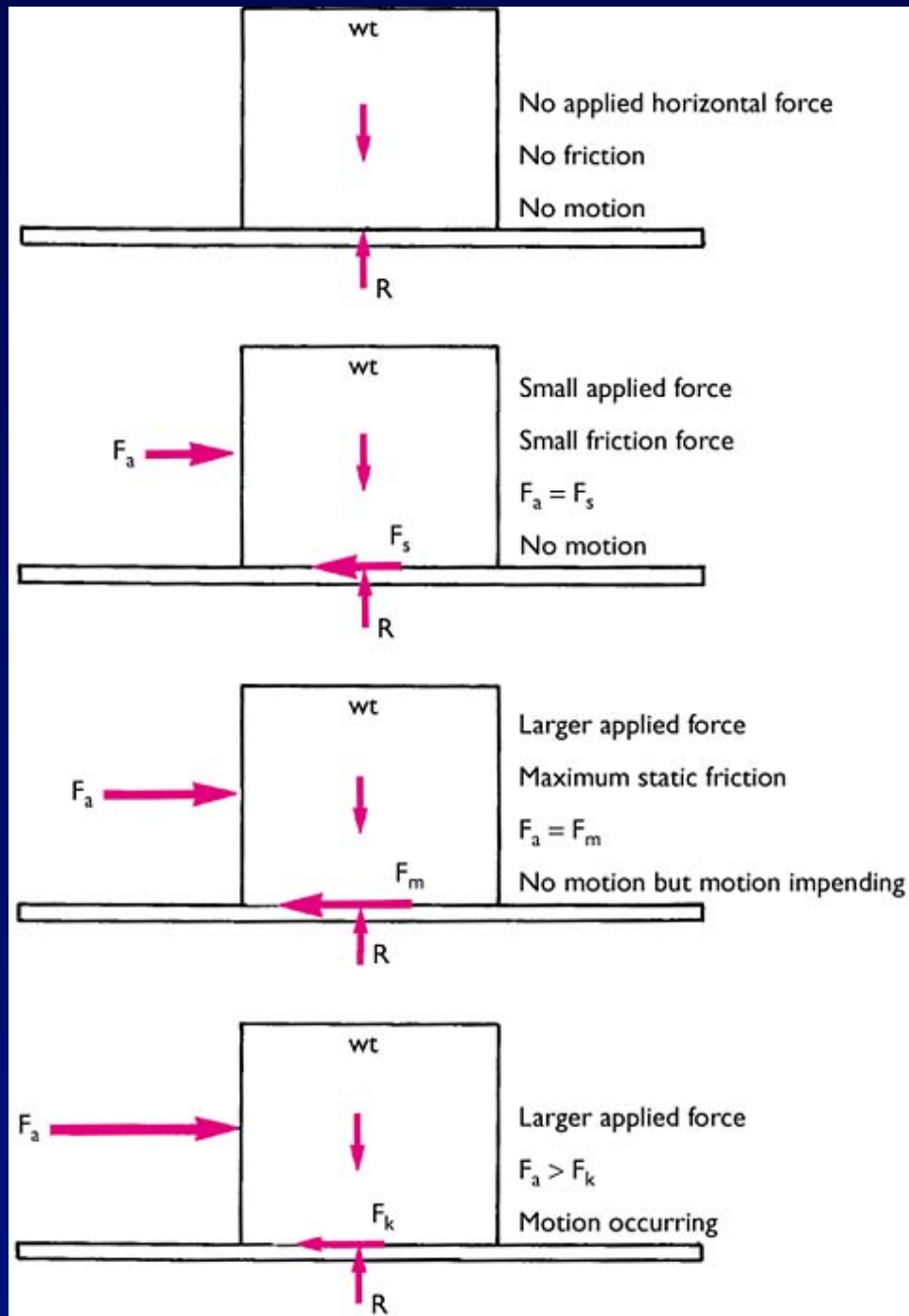
- Coefficient of kinetic friction (μ_k):

Normal reaction force:

Rolling friction:

Friction

- **Friction:** force acting over the area of contact between two surfaces in the direction opposite that of motion or motion tendency
- Because friction is a force, it is quantified in units of force (N).

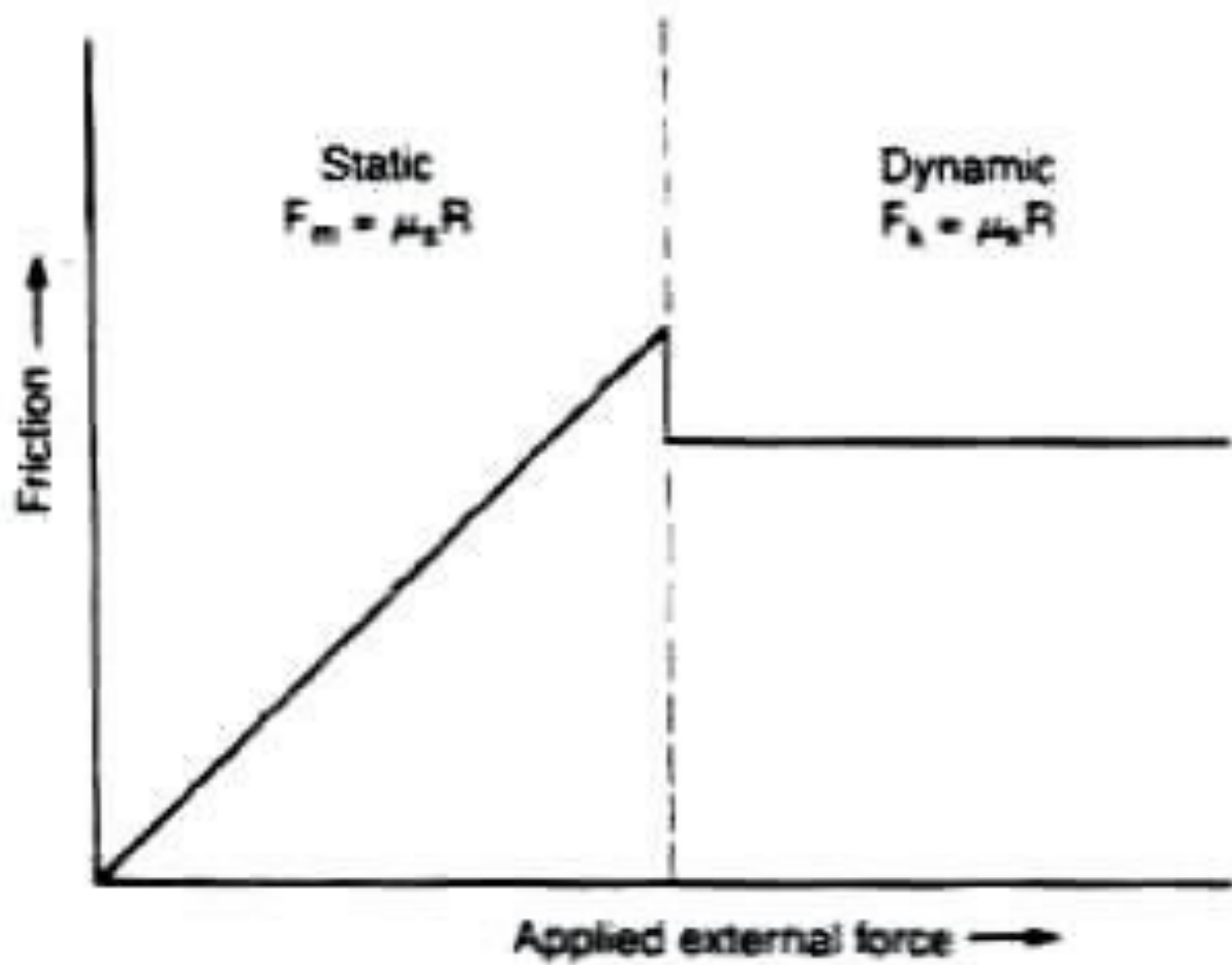


Maximum static friction

- maximum amount of friction that can be generated between two surfaces

Kinetic friction

- constant-magnitude friction generated between two surfaces in contact during motion



Magnitude of Friction

- Two factors govern the magnitude of the force or maximum static friction or kinetic friction in any situation: the coefficient of friction, represented by the small Greek letter mu (μ), and the normal (perpendicular) reaction force (R).

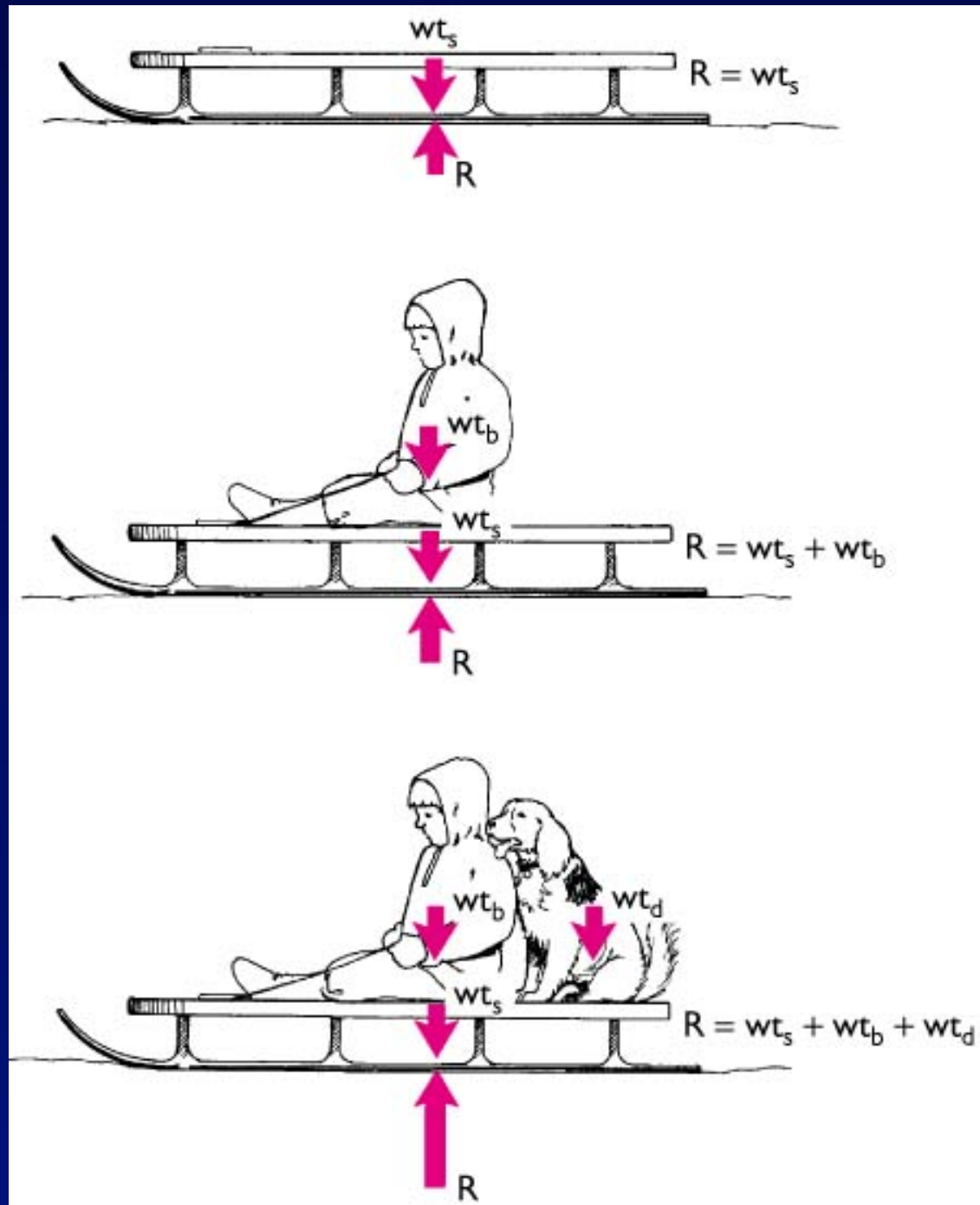
- $$F = \mu R$$

Coefficient of friction

- **Coefficient of friction:** number that serves as an index of the interaction between two surfaces in contact
- **Coefficient of static friction:** for motionless bodies in contact
- **Coefficient of kinetic friction:** for bodies in contact and in motion

Normal reaction force

- force acting perpendicular to two surface in contact



Rolling friction

- is influenced by the weight, radius, and deformability of the rolling object, as well as by the coefficient of friction between the two surfaces.

Mechanical Behavior of Bodies in Contact

Linear Momentum:

- $M = mv$
- Units - $\text{kg} \cdot \text{m/s}$

Principle of conservation of momentum:

In the absence of external forces, the total momentum of a given system remains constant

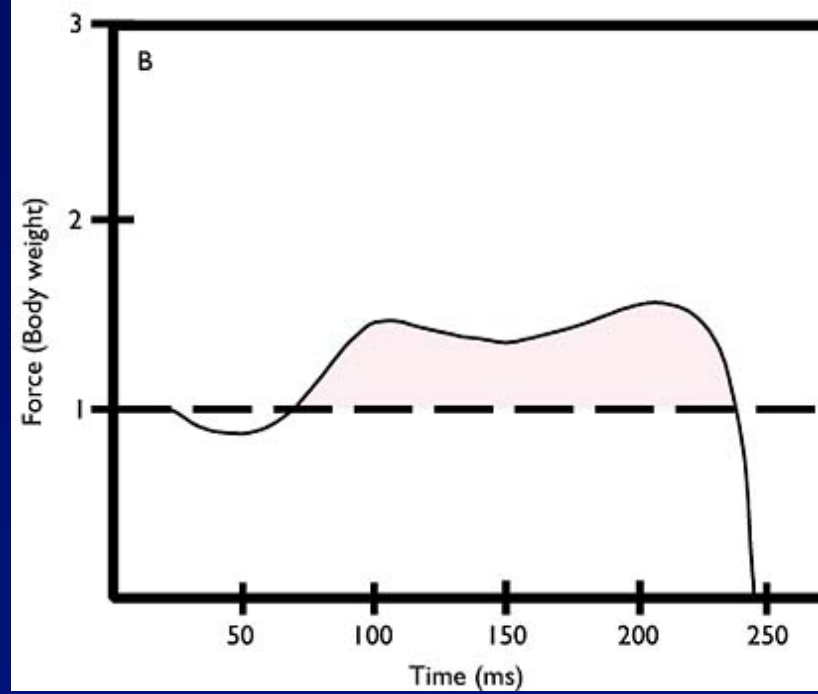
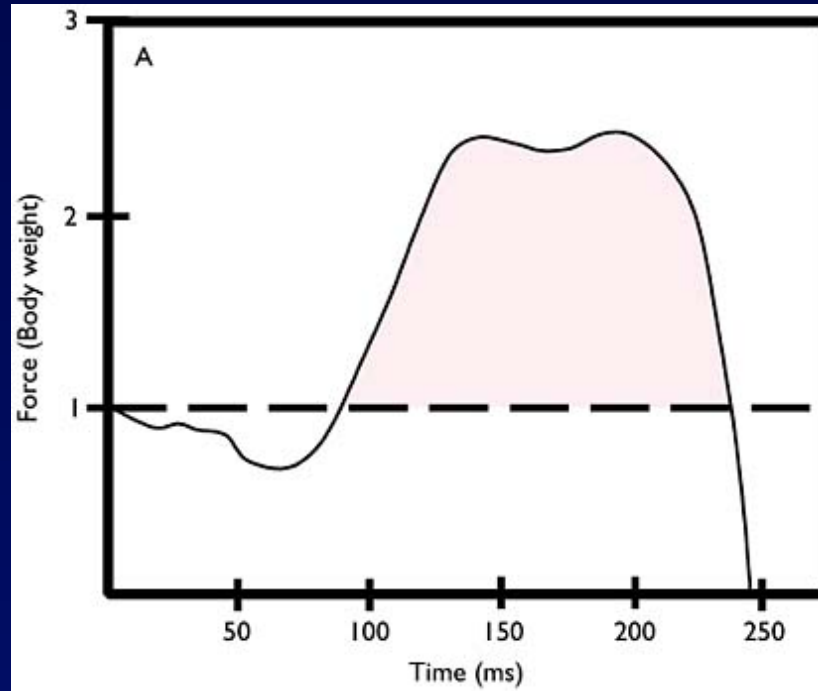
Mechanical Behavior of Bodies in Contact

Impulse:

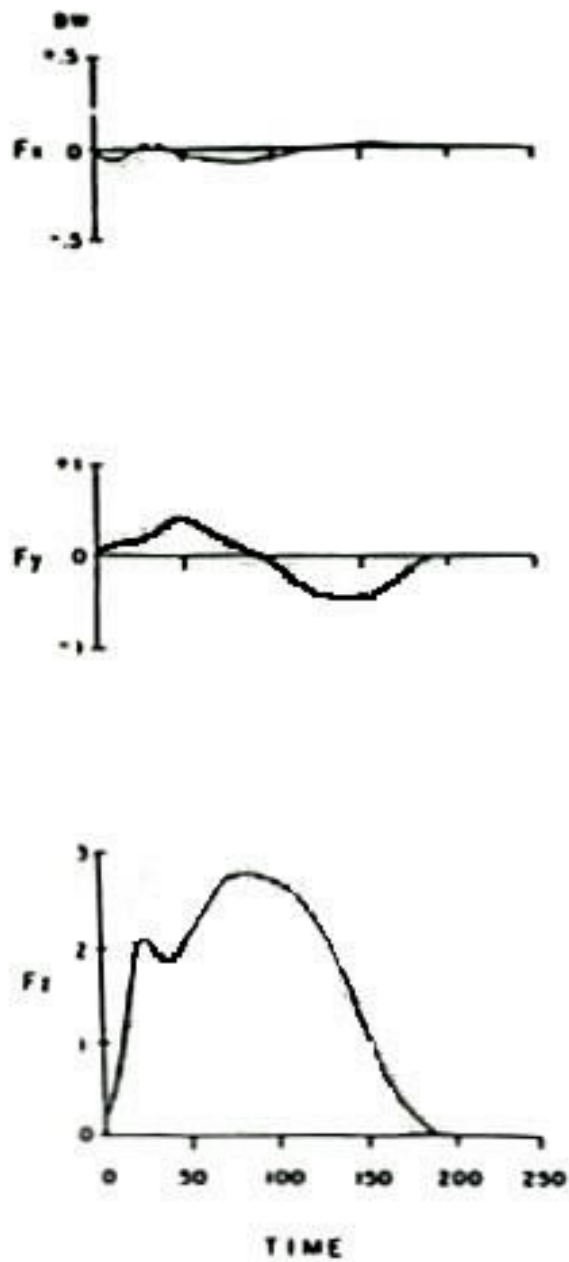
- Impulse = Ft

Derived from Newton's Second law:

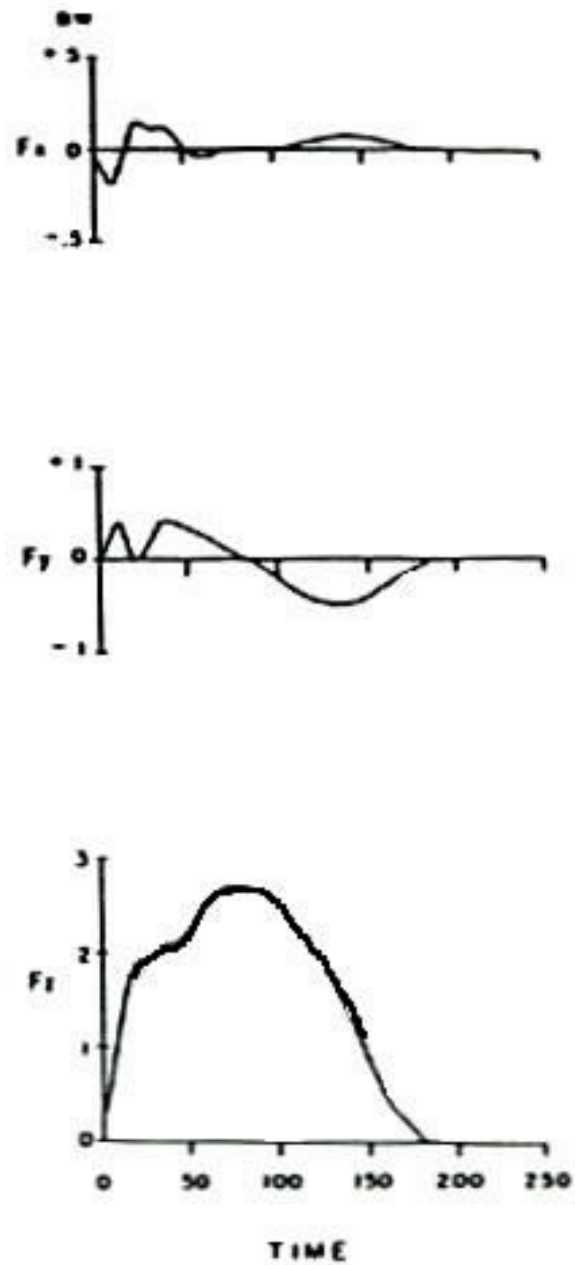
- $F = ma$
- $F = m ([v_2 - v_1] / t)$
- $Ft = (mv_2) - (mv_1)$
- $Ft = \Delta M$



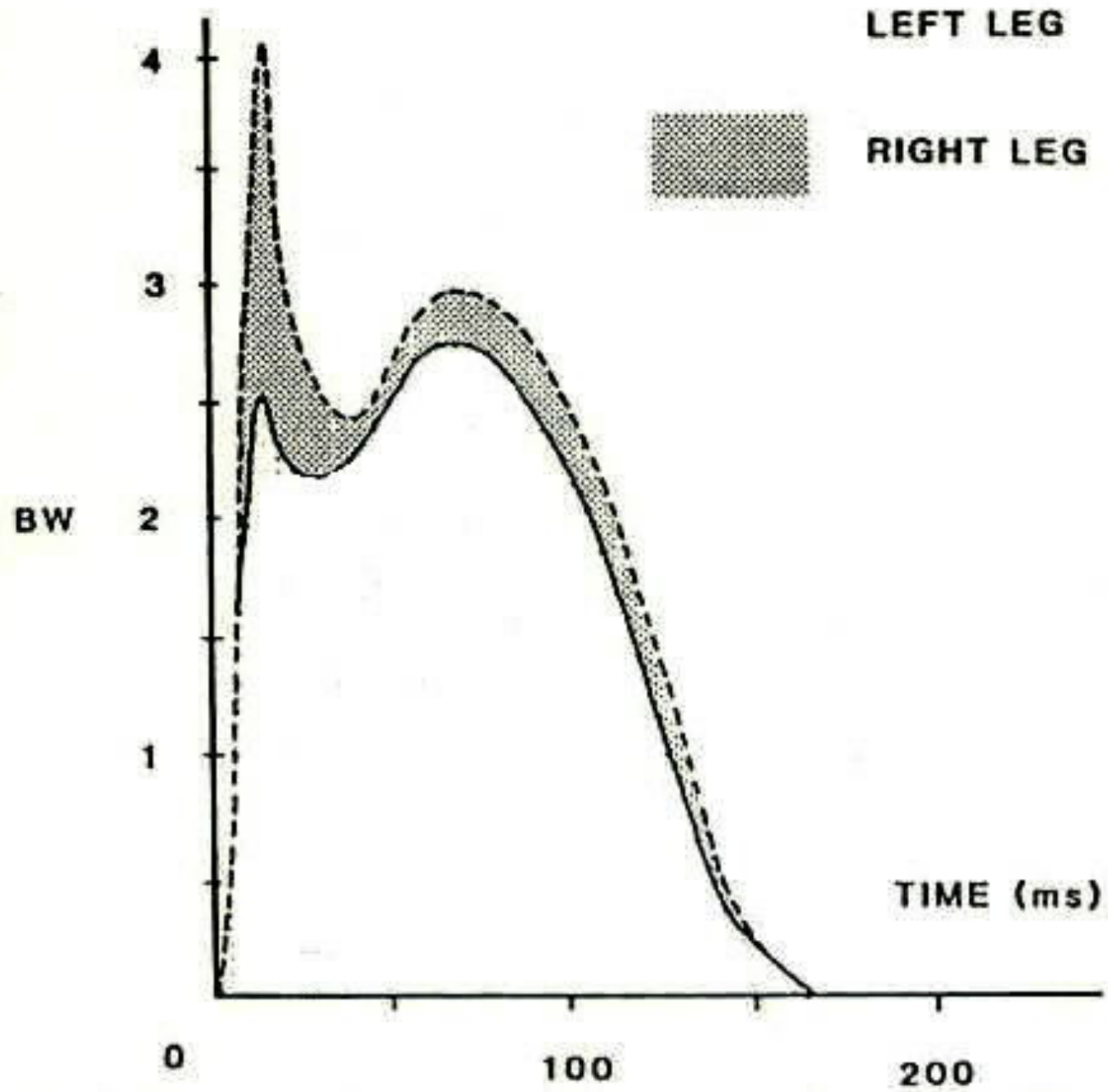
REARFOOT



MIDFOOT



FORCE - F_z



Mechanical Behavior of Bodies in Contact

Impact:

Perfectly elastic impact:

Perfectly plastic impact:

Coefficient of restitution:

Impact

- collision characterized by exchange of a large force during a small time interval

Perfectly elastic impact

- Impact during which the velocity of the system is conserved

Perfectly plastic impact

- Impact resulting in the total loss of system velocity

Impact = $F \cdot t$



Coefficient of restitution

- number that serves as an index of elasticity for colliding bodies
- The coefficient of restitution describes the relative elasticity of an impact.

Mechanical Behavior of Bodies in Contact

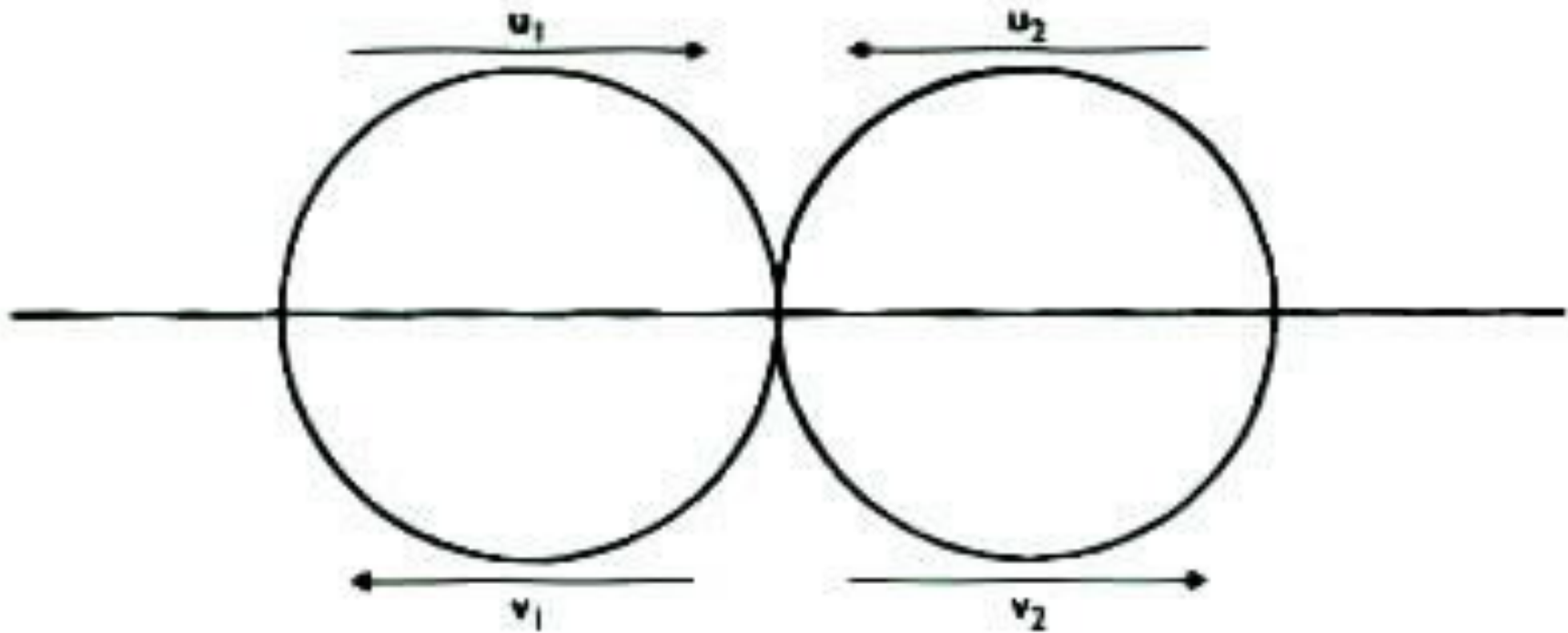
Impact (cont.)

Newton:

When two bodies undergo a direct collision, the difference in their velocities immediately after impact is proportional to the difference in their velocities immediately before impact

$$-e = \frac{\text{relative velocity after impact}}{\text{relative velocity before impact}} = \frac{v_1 - v_2}{u_1 - u_2}$$

Ball velocities before impact



Ball velocities after impact

$$v_1 - v_2 = -e (u_1 - u_2)$$

Work, Power & Energy Relationships

Work

Work = Force • Distance

$$W = Fd$$

- Positive work:
- Negative work:
- Common units: joule (J)

Mechanical work \neq caloric expenditure

Work

- **Positive work:** when both the net muscle torque and the direction of angular motion at a joint are in the same direction
- **Negative work:** when the net muscle torque and the direction of angular motion at a joint are in opposite directions

Work

- Units of work are units of force multiplied by units of distance.
- In the metric system, the common unit of force (N) multiplied by a common unit of distance (m) is term the **joule (J)**.
- Mechanical work should not be confused with caloric expenditure.

Work, Power & Energy Relationships

Power

$$\text{Power} = \frac{\text{Work}}{\text{change in time}} = \frac{W}{\Delta t}$$

$$\text{Power} = \frac{\text{force} \times \text{distance}}{\text{change in time}} = \frac{Fd}{\Delta t}$$

$$\text{Since } v = d / \Delta t, \quad \text{Power} = Fv$$

$$\text{Units - watts (W)} \quad 1 \text{ W} = 1 \text{ J/s}$$

Work, Power & Energy Relationships

Energy

Energy: the capacity to do work

Units are the same as work - joules

Kinetic energy, $KE = 1/2 mv^2$

Potential energy, $PE = wt \cdot h = ma_g h$

Strain energy, $SE = 1/2 kx^2$

Conservation of Mechanical Energy

- Consider a ball tossed vertically into the air

Law of conservation of mechanical energy:

- When gravity is the only acting external force, a body's mechanical energy remain constant
- $(PE + KE) = C$

Principle of Work & Energy

- The work of a force is equal to the change in energy that it produces on the object acted on
- $W = \Delta KE + \Delta PE + \Delta TE$

Mechanical work \neq caloric expenditure

- ~25% of energy consumed by muscle is converted into work

Implications for Equipment Design

- Tennis rackets
- Golf clubs
- Running shoes/track surfaces

Three forms of Newton's Second Law

- **F = ma**: used to calculate the instantaneous value of force
- **Impulse-Momentum**: used to calculate the effect of a force applied over an interval of time
- **Work-Energy**: used to examine the effect of a force that causes an object to move through some distance

Summary

- Linear kinetics is the study of the forces associated with linear motion
- Friction is a force generated at the interface of two surfaces in contact
- Magnitudes of maximum static friction and kinetic friction are determined by the coefficient of friction and normal reaction force pressing the two surfaces together.
- Linear momentum is the product of an object's mass and its velocity

Summary

- Total momentum in a given system remains constant barring the action of external forces
- Changes in momentum result from impulses, external forces acting over a time interval
- The elasticity of an impact governs the amount of velocity in the system following impact
- The relative elasticity of is represented by the coefficient of restitution
- Mechanical work is the product of force and the distance through which the force acts

Summary

- Mechanical power is the mechanical work done over a time interval
- Mechanical energy has two forms: kinetic and potential
- When gravity is the only acting external force, the sum of the kinetic and potential energies possessed by a given body remains constant
- Changes in a body's energy are equal to the mechanical work done by an external force

The End