Biophysics

Lecture 3: The Laws of Kinetic Physics and Interpretation of Mechanical Motion of Bodies

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Course Information

Course: Biophysics
Level: First Year Students
Department: Medical Biotechnology

1 Concept of Motion in Biological Systems

Motion is a fundamental characteristic of living systems. Unlike inert objects, biological motion is purposeful, regulated, and energy-dependent. Examples include muscle contraction, blood circulation, respiratory movement, cellular transport, and molecular motion within the cytoplasm.

To understand these processes quantitatively, biological motion must be analyzed using the laws of kinetic physics. These laws allow us to describe how biological bodies move, how fast they move, and how their motion changes under the action of forces.

2 Kinetic Physics: Scope and Significance

Kinetic physics (kinematics and dynamics) is a branch of classical mechanics concerned with the description and interpretation of motion. It provides tools to analyze motion independently of its biological origin.

In biophysics, kinetic physics is essential for:

- Quantitative analysis of human movement
- Understanding blood and airflow dynamics
- Studying mechanical behavior of tissues
- Designing medical and rehabilitation devices

3 Reference Frame and Relativity of Motion

Motion is not absolute; it is always measured relative to a reference frame. A reference frame consists of a coordinate system and a time scale.

For example, blood may be stationary relative to the vessel wall but moving relative to the heart. Proper interpretation of biological motion requires choosing an appropriate reference frame.

4 Mechanical Motion

Mechanical motion is defined as the change in position of a body with respect to time relative to a chosen reference frame. A body whose position does not change with time is considered at rest.

Mechanical motion can be analyzed using equations, graphs, and experimental measurements, making it suitable for quantitative biological analysis.

5 Classification of Mechanical Motion

Mechanical motion is classified into three fundamental types:

Translational Motion

All points of the body move the same distance in the same direction. Examples include walking, blood flow, and movement of cells.

Rotational Motion

The body rotates about a fixed axis, such as rotation of joints or limbs.

Oscillatory Motion

Repetitive motion about an equilibrium position, such as heartbeat, breathing, and muscle vibrations.

Most biological motions involve a combination of these types.

6 Kinematic Quantities

The description of motion relies on measurable physical quantities:

- **Position** (x): spatial location
- **Displacement** (Δx): change in position
- **Velocity** (v): rate of change of displacement
- **Acceleration** (a): rate of change of velocity

Mathematically:

$$v = \frac{dx}{dt}, \qquad a = \frac{dv}{dt}$$

These quantities are essential for analyzing biomechanical and physiological motion.

7 Uniform and Non-Uniform Motion

Uniform motion occurs when velocity remains constant with time, resulting in zero acceleration.

Non-uniform motion occurs when velocity changes, producing acceleration. Most biological motions are non-uniform due to varying muscular forces and external resistance.

8 Newton's Laws of Motion

Newton's laws form the foundation of kinetic physics.

First Law (Inertia)

A body remains at rest or in uniform motion unless acted upon by an external force. This law explains why muscle activation is required to initiate or stop movement.

Second Law

$$F = ma$$

This law quantifies the relationship between applied force and resulting motion, explaining why heavier body parts require greater muscular force.

Third Law

For every action, there is an equal and opposite reaction. This principle is essential for walking, running, and swimming.

9 Forces Acting in Biological Systems

Biological motion results from the interaction of several forces:

- Muscular forces
- Gravitational force
- Frictional forces
- Elastic forces in tendons and tissues

The net force determines the acceleration of the body.

10 Mechanical Work and Energy

Mechanical work is done when a force produces displacement:

$$W = Fd\cos\theta$$

Kinetic energy is the energy associated with motion:

$$KE = \frac{1}{2}mv^2$$

These concepts are crucial for understanding energy expenditure in biological movement and physiological processes.

11 Relevance to Medical Biotechnology

Understanding kinetic physics enables medical biotechnologists to:

- Analyze human movement disorders
- Design prosthetic and orthopedic devices
- Improve rehabilitation techniques
- Optimize biomechanical performance

12 Multiple Choice Questions (MCQs)

Q1. Biological motion is best described as
A- random and uncontrolled
B- independent of physical laws
C- purposeful and governed by physics
D- purely chemical
E- None of them

Q2. Kinetic physics primarily studies
A- heat and temperature
B- motion and its description
C- atomic structure
D- chemical reactions
E- None of them

Q3. Motion must always be described relative to a
A- force
B- mass
C- reference frame
D- velocity
E- None of them

Q4. A body is at rest if its position
A- changes slowly
B- does not change with time
C- changes direction
D- changes energy
E- None of them

Q5. Walking mainly involves
A- rotational motion only
B- oscillatory motion only
C- translational motion
D- random motion
E- None of them

Q6. Velocity is defined as the rate of change of
A- force
B- displacement
C- acceleration

D- mass
E- None of them

Q7. Acceleration represents
A- change in position
B- change in velocity
C- total distance
D- force only
E- None of them

Q8. Most biological motions are
A- uniform
B- non-uniform
C- static
D- imaginary
E- None of them

Q9. Newton's first law explains the concept of
A- energy
B- inertia
C- momentum
D- work
E- None of them

Q10. Newton's second law is expressed as
A- $F = mv$
B- $F = ma$
C- $F = m/a$
D- $F = a/m$
E- None of them

Q11. Which force is produced by muscle contraction?
A- Electric
B- Magnetic
C- Muscular
D- Nuclear
E- None of them

Q12. Frictional force generally
A- increases motion
B- resists motion
C- creates energy
D- eliminates gravity
E- None of them

Q13. Mechanical work is done when a force
A- acts without movement
B- causes displacement
C- increases mass
D- changes temperature
E- None of them

Q14. The SI unit of work is

A- watt
B- newton
C- joule
D- pascal
E- None of them

Q15. Kinetic energy depends on

A- mass only
B- velocity only
C- mass and velocity
D- force only
E- None of them

Q16. Blood circulation analysis mainly uses

A- optics
B- kinetic physics
C- nuclear physics
D- thermochemistry
E- None of them

Q17. Biomechanics is an application of

A- genetics
B- biophysics
C- chemistry
D- microbiology
E- None of them

Q18. Prosthetic design relies heavily on

A- chemical bonding
B- kinetic physics principles
C- plant physiology
D- immunology
E- None of them

Q19. Correct interpretation of motion requires

A- ignoring forces
B- selecting a reference frame
C- avoiding equations
D- using chemistry only
E- None of them

Q20. Kinetic physics is essential in medical biotechnology because it

A- replaces biology
B- ignores motion
C- explains biological movement quantitatively
D- studies only machines
E- None of them