

Energy

- Ability to do work
- Measured in joules (J)
- One joule is the work done when a one newton force moves an object through one metre
- 1 Calorie = 1000 cal = 4.186 kJ
- Can take many forms

Forms of Energy

- Mass ($E = mc^2$)
- Solar or Light (solar panels, photovoltaic battery)
- Electricity (electron flux, magnetic induction)
- Chemical (fossil fuels, ATP, food)
- Thermal or Heat
- Mechanical energy

Types of Mechanical Energy

- Translational Kinetic = $\frac{1}{2} m v^2$
 - $v^2 = v_x^2 + v_y^2 (+ v_z^2)$
 - this is usually the largest type in biomechanics
- Rotational Kinetic = $\frac{1}{2} I \omega^2$
 - this is usually the smallest type in biomechanics
- Gravitational Potential = $m g y$
- Elastic Potential = $\frac{1}{2} k (x_1^2 - x_2^2)$
 - Assumed to be zero for rigid bodies

Laws of Thermodynamics

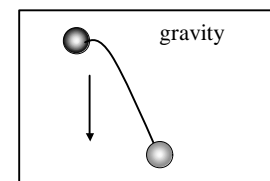
- Zeroth law
 - When two quantities are in thermal balance to a third they are in thermal balance with each other. I.e., they have the same temperature.
- First Law (Law of Conservation of Energy)
 - Energy is conserved (remains constant) within a “closed system.”
 - Energy cannot be created or destroyed.
- Second Law (Law of Entropy)
 - When energy is transformed from one form to another there is always a loss of usable energy.
 - All processes increase the entropy of the universe.
- Third Law
 - Absolute zero (absence of all atomic motion) cannot be achieved.

Law of Conservation of Mechanical Energy

- If the resultant force acting on a body is a conservative force then the body's total mechanical energy will be conserved.
- Resultant force will be conservative if all external forces are conservative.
- A force is conservative if it does no work around a closed path (motion cycle).

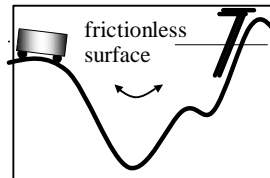
Examples of Conservative Forces

- Gravitational forces



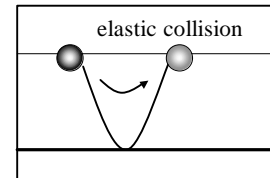
Examples of Conservative Forces

- Gravitational forces
- Normal force of a frictionless surface



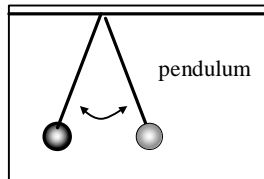
Examples of Conservative Forces

- Gravitational forces
- Normal force of a frictionless surface
- Elastic collisions



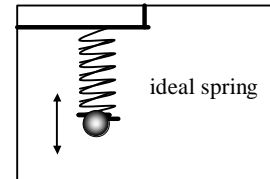
Examples of Conservative Forces

- Gravitational forces
- Normal force of a frictionless surface
- Elastic collisions
- Ideal pendulum



Examples of Conservative Forces

- Gravitational forces
- Normal force of a frictionless surface
- Elastic collisions
- Ideal pendulum
- Spring forces



Direct Ergometry

- Treadmill ergometry
- External work = $m g t v \sin \theta$
- where, m = mass, $g = 9.81$, t = time, v = treadmill velocity, and θ = treadmill's angle of incline



Direct Ergometry

- Cycle ergometry
- External work = $6 n L g$
- where, n = number of pedal revolutions, L = load in kiloponds and $g = 9.81$
- Note, each pedal cycle is 6 metres motion of flywheel



Direct Ergometry

- Guessing rowing ergometry
- External work = $n L g$
- where, n = number of flywheel cycles, L = workload in kiloponds and $g = 9.81$



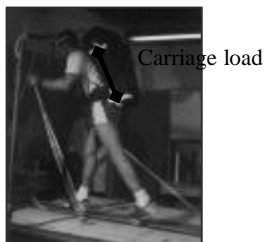
Biomechanical Methods

- Point mass method
 - Simplest, least accurate, ignores rotational energy
- External work = $m g y + \frac{1}{2} m v^2$



Biomechanical Methods

- Single rigid body method
 - Simple, usually planar, includes rotational energy
- External work = $mgy + \frac{1}{2} mv^2 + \frac{1}{2} I \omega^2$



Biomechanical Methods

- Multiple rigid body method
 - Difficult, usually planar, more accurate, accuracy increase with number of segments
- External work = $E_{final} - E_{initial}$
- E = sum of segmental total energies (kinetic plus potential energies)



Physiological Methods

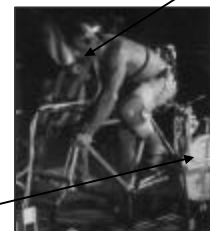
- Oxygen uptake
 - Difficult, accurate, expensive, invasive
- External work = $c (VO_2)$
- Where, c is the energy released by metabolizing O_2 and VO_2 is the volume of O_2 consumed



Mechanical Efficiency

- Measure both mechanical and physiological costs
- ME = mechanical cost divided by physiological cost times 100%

Monark ergometer used to measure mechanical work done



Mouthpiece for collecting expired gases and physiological costs

Mechanical Efficiency

$$ME = \frac{\text{Internal work} + \text{External work}}{\text{Physiological cost}} \times 100 \%$$

Internal work is measured by adding up the work done by all the joint moments of force. Most researchers ignore the internal work done.

Work of a Force

Work of a force is product of force (F) and displacement (s) when F and s are in the same direction.

$$\begin{aligned} \text{Work} &= F s && \text{(when F is parallel to s)} \\ &= F s \cos \theta && \text{(when F is not parallel to s)} \\ &&& \text{and } \theta \text{ is } \theta \text{ angle between F and s} \\ &= \underline{F} \cdot \underline{s} = F_x s_x + F_y s_y && \text{(dot or scalar product)} \\ &= E_f - E_i && \text{(change of energy)} \\ &= P t && \text{(power times time)} \end{aligned}$$

Work of a Moment of Force

Work of a moment of force is product of moment of force (M) and angular displacement (θ).

$$\begin{aligned} \text{Work} &= M \theta \\ &= r F (\sin \theta) && \theta \text{ is angle between } r \text{ and } F \\ &= P t && \text{(power times time)} \end{aligned}$$

Average Power

Power is the rate of doing work.
measured in watts (W), 1 watt = 1 joule per second (J/s)

$$\begin{aligned} \text{Power} &= \text{work} / \text{time} && \text{(work rate)} \\ &= (E_f - E_i) / \text{time} && \text{(change in energy over time)} \\ &= (F s) / t = F v && \text{(force times velocity)} \\ &= (M \theta) / t = M \omega && \text{(moment of force times angular velocity)} \end{aligned}$$

Instantaneous Power of a Force or Moment of Force

$$\begin{aligned} \text{Power} &= F v && \text{(when F is parallel to } v) \\ &= F v \cos \theta && \text{(when F is not parallel to } v) \\ &&& \text{and } \theta \text{ is } \theta \text{ angle between F and } v \\ &= \underline{F} \cdot \underline{v} = F_x v_x + F_y v_y && \text{(dot or scalar product)} \\ &= M \omega && \text{(moment times angular velocity)} \end{aligned}$$

Isokinetic Dynamometers

- Controls speed of motion therefore lever has constant angular velocity (ω)
- Measures force against a lever arm
- Moment = force times lever arm
- Instantaneous power = moment time angular velocity

