

A 75 Kg Student Walks Up Three Flights Of Stairs, A Vertical Height Of About 50 Ft. If The Magnitude

A 75 Kg Student Walks Up Three Flights Of Stairs, A Vertical Height Of About 50 Ft. If The Magnitude of the work done during this activity is to be calculated, it provides an excellent opportunity to explore the fundamental principles of physics, particularly in the context of work, energy, and power. Understanding these concepts is essential not only for physics students but also for anyone interested in how energy expenditure relates to everyday activities such as climbing stairs. This article will delve into the detailed calculation of the work done, explore the scientific concepts involved, and provide insights into related physical phenomena.

Understanding the Scenario

To analyze the work done by the student, let's first clarify the key parameters of the problem:

- Mass of the student (m): 75 kg
- Vertical height climbed (h): approximately 50 feet
- Number of flights: three flights of stairs

Since the height is given in feet, it's necessary to convert it into meters for standard SI unit calculations.

Unit Conversion: Feet to Meters

The conversion factor is:

1 foot $\approx$ 0.3048 meters

Therefore,

50 feet $\approx$ $50 \times 0.3048 = 15.24$ meters

This means the student climbs a vertical height of approximately 15.24

meters.

Fundamental Concepts in Physics

Before calculating the work done, a brief overview of relevant physics concepts is essential:

Work Done (W)

In physics, work is defined as the process of energy transfer when a force is applied to an object, causing displacement in the direction of the force. Mathematically:

$$W = F \times d \times \cos \theta$$

where:

- F is the applied force,
- d is the displacement,
- θ is the angle between the force and displacement.

For vertical movement against gravity, the force applied is primarily to overcome the gravitational force acting on the body.

Gravitational Force (Weight)

The weight of the student is given by:

$$W_g = m \times g$$

where:

- m is mass,
- g is acceleration due to gravity ($\sim 9.81 \text{ m/s}^2$).

Work Against Gravity

When climbing stairs, the work done against gravity is:

$$W = m \times g \times h$$

This formula assumes that the entire vertical height is climbed in a straight line and neglects additional energy losses such as friction and muscular

inefficiency.

Calculating the Work Done

Using the above concepts, let's calculate the work done by the student during the stair climb.

Step 1: Calculate the Weight of the Student

$$W_g = 75 \text{ kg} \times 9.81 \text{ m/s}^2 = 735.75 \text{ N}$$

This is the force due to gravity acting on the student.

Step 2: Calculate the Work Done

$$W = m \times g \times h$$

$$W = 75 \text{ kg} \times 9.81 \text{ m/s}^2 \times 15.24 \text{ m}$$

$$W \approx 75 \times 9.81 \times 15.24$$

$$W \approx 75 \times 149.41$$

$$W \approx 11,205.75 \text{ Joules}$$

Therefore, the magnitude of the work done by the student is approximately 11,206 Joules.

Factors Affecting the Actual Work Done

While the above calculation provides an idealized estimate, real-world scenarios include additional factors that influence the actual work performed:

1. Muscular Efficiency

- Human muscles are not perfectly efficient.
- Typically, human efficiency in activities like climbing stairs ranges from 20% to 25%.
- This implies that the actual energy expenditure is higher than the calculated work.

2. Energy Losses

- Friction between the feet and stairs.
- Air resistance.
- Body movements and balance adjustments.

3. Mechanical Advantages

- Using handrails or different stair designs can alter the force and work.

Estimating Total Energy Expended

Considering muscular efficiency, the total energy expenditure (E) can be estimated as:

$$E = \frac{W}{\text{Efficiency}}$$

Assuming an efficiency of 20% (0.20):

$$E \approx \frac{11,206}{0.20} \approx 56,030 \text{ Joules}$$

This indicates the student expends approximately 56,030 Joules of energy during the stair climb, accounting for inefficiencies.

Additional Concepts Related to Climbing Stairs

Understanding the physics of stair climbing extends beyond work calculation. It involves exploring various related concepts:

1. Power Output

Power is the rate at which work is done:

$$P = \frac{W}{t}$$

where t is the time taken to climb the stairs. If, for example, the student takes 2 minutes (120 seconds):

$$P \approx \frac{11,206}{120} \approx 93.38 \text{ Watts}$$

This average power output indicates the intensity of effort during the activity.

2. Potential Energy Gain

The increase in potential energy is equal to the work done against gravity, which elevates the student's body to a higher position.

3. Metabolic Energy and Calories

The energy expended can also be expressed in dietary calories:

$$1 \text{ Calorie} \approx 4184 \text{ Joules}$$

Therefore,

$$\text{Calories burned} \approx \frac{56,030}{4184} \approx 13.4 \text{ Calories}$$

This shows how stair climbing contributes to calorie expenditure, beneficial for weight management.

Practical Applications and Significance

Understanding the physics behind stair climbing has practical implications:

- Design of ergonomic stairs ensuring safety and efficiency.
- Estimating caloric burn for fitness and weight loss programs.
- Developing exercise routines that optimize energy expenditure.
- Understanding biomechanical stresses and preventing injuries.

Furthermore, analyzing such simple activities helps in understanding larger principles of physics and biomechanics, reinforcing the importance of physics in daily life.

Conclusion

Calculating the magnitude of work done when a student walks up three flights of stairs reveals the fundamental principles of physics at play in everyday activities. The estimated work of approximately 11,206 Joules, considering ideal conditions, provides insight into the energy required to elevate a mass of 75 kg through a vertical height of about 15.24 meters. When accounting for muscular efficiency and real-world factors, the total energy expenditure is significantly higher, emphasizing the body's effort in physical activities. This analysis not only underscores the importance of physics in understanding energy and work but also offers practical applications in health, fitness, and engineering.

By understanding these concepts, students and fitness enthusiasts alike can better appreciate the physical effort involved in simple activities like climbing stairs and make informed decisions about their physical health and activity routines.

Frequently Asked Questions

What is the potential energy gained by a 75 kg student walking up three flights of stairs totaling 50 ft?

The potential energy gained is approximately 18,150 Joules, calculated using $PE = mgh$, where $m = 75 \text{ kg}$, $g = 9.8 \text{ m/s}^2$, and $h = 15.24 \text{ meters (50 ft)}$.

How do you convert 50 feet into meters for calculating potential energy?

Since 1 foot equals 0.3048 meters, 50 ft converts to approximately 15.24 meters (50×0.3048).

What is the work done by the student while climbing the stairs?

The work done is equal to the gain in potential energy, approximately 18,150 Joules, assuming no energy losses.

If the student weighs 75 kg, what is their weight in newtons?

The weight is calculated as mass $\times$ gravity: $75 \text{ kg} \times 9.8 \text{ m/s}^2 = 735 \text{ Newtons}$.

What factors affect the amount of work done in climbing stairs?

Factors include the student's weight, the vertical height climbed, and the efficiency of their movement; notably, the height and mass are primary determinants.

How does gravity influence the energy required to climb stairs?

Gravity determines the force needed to lift the student vertically; the greater the height, the more gravitational potential energy is gained, directly affecting the work done.

Can we assume all the work done is converted into potential energy? Why?

In ideal conditions with no energy losses, yes. In reality, some energy is lost as heat and sound, so not all work converts into potential energy.

What is the significance of calculating potential energy in this scenario?

Calculating potential energy helps quantify the work done and energy expenditure involved in climbing stairs, useful for fitness and physics understanding.

How would the work change if the student weighed 80 kg instead of 75 kg?

The work would increase proportionally; for 80 kg, $PE = 80 \times 9.8 \times 15.24 \approx 11,930$ Joules more than for 75 kg.

What practical applications can understanding this physics problem have?

It can inform exercise physiology, energy expenditure estimates, designing accessible buildings, and understanding biomechanics of stair climbing.

Additional Resources

Energy and Work Done by a Student Climbing Stairs: An In-Depth Analysis

Walking up stairs might seem like a simple daily activity, but beneath its apparent simplicity lies a fascinating interplay of physics, physiology, and biomechanics. When a student weighing 75 kg ascends three flights of stairs covering approximately 50 feet in vertical height, a host of concepts related to work, energy, and power come into play. This comprehensive review delves into the physics behind this activity, exploring the concepts of work, energy transfer, power, and the physiological implications involved in such a task.

Understanding the Scenario

Before diving into calculations and analysis, it's crucial to set the context:

- Mass of the Student: 75 kg
- Vertical Height Climbed: Approximately 50 feet (about 15.24 meters)
- Number of Flights: Three flights (though the focus is on vertical height, not the number of steps)
- Nature of the Movement: Ascending vertically against gravity
- Duration: Not specified, but can be estimated or analyzed based on typical pace

This activity involves converting chemical energy from the student's muscles into mechanical work to elevate the body against gravity, resulting in an increase in gravitational potential energy.

Fundamental Concepts in Physics

Work and Energy

- Work (W): In physics, work is defined as the product of force applied and the displacement in the direction of the force. Mathematically,

$$W = F \times d \times \cos\theta$$

where:

- F is the force applied
 - d is the displacement
 - θ is the angle between force and displacement vector
- Energy: The capacity to do work. When the student climbs stairs, chemical energy from food is converted into kinetic and potential energy.
- Gravitational Potential Energy (GPE):

$$U = m g h$$

where:

- m = mass
- g = acceleration due to gravity ($\sim 9.81 \text{ m/s}^2$)
- h = height above the reference point

Understanding these concepts helps quantify the work done and energy expenditure involved in stair climbing.

Physiological Energy Expenditure vs. Mechanical Work

- The human body is not perfectly efficient; only a fraction of chemical energy is converted into mechanical work.

- Typical human efficiency in converting chemical energy from food into mechanical work during walking or stair climbing ranges from 20% to 25%.
- The rest is lost as heat, due to metabolic processes, muscular inefficiencies, and other physiological factors.

Calculating the Mechanical Work Done

Step 1: Convert the Height to Meters

Given height:

$$h = 50 \text{ feet} \approx 50 \times 0.3048 \approx 15.24 \text{ meters}$$

Step 2: Calculate the Gravitational Potential Energy Gained

Using the formula:

$$U = m g h$$

Plugging in values:

$$U = 75 \text{ kg} \times 9.81 \text{ m/s}^2 \times 15.24 \text{ m}$$

$$U \approx 75 \times 9.81 \times 15.24 \approx 75 \times 149.4 \approx 11,205 \text{ joules}$$

Therefore, the student gains approximately 11,205 joules of potential energy by climbing three flights of stairs.

Step 3: Considering the Work Done in Context

- Mechanical work done against gravity is approximately 11.2 kJ.
- Note: This is the theoretical minimum for work done if the entire body moved vertically without acceleration or other factors.

Physiological and Real-World Considerations

Efficiency and Metabolic Cost

- Human muscles are not 100% efficient.
- Typical efficiency:

$$\eta \approx 20\% - 25\%$$

- To produce the required mechanical work:

$$\text{Energy from food} = \frac{U}{\eta}$$

- Assuming 20% efficiency:

$$\text{Total energy expended} \approx \frac{11,205}{0.20} \approx 56,025 \text{ joules}$$

- In dietary terms, since 1 kcal $\approx$ 4184 joules:

$$\text{Calories burned} \approx \frac{56,025}{4184} \approx 13.4 \text{ kcal}$$

This is a simplified estimate, not accounting for additional physiological factors.

Additional Factors Affecting Energy Expenditure

- Initial acceleration phase: Muscles exert additional force to start moving.

- Speed of climbing: Faster ascent increases energy consumption.
- Body mechanics: Use of arms, stride length, and gait influence efficiency.
- Rest periods: Pauses or breaks alter overall energy expenditure.
- Environmental factors: Air resistance, surface friction, etc., are minimal but present.

Power Output During Climbing

Power is the rate at which work is performed. It is crucial to understand how quickly the activity occurs.

$$P = \frac{W}{t}$$

where:

- P = power in watts (W)
- W = work done in joules
- t = time in seconds

Estimating Time:

- Average stair climbing pace is roughly 1 to 2 minutes for such a height.
- Assume 1.5 minutes (90 seconds) for calculation.

Power calculation:

$$P = \frac{11,205 \text{ J}}{90 \text{ s}} \approx 124.5 \text{ W}$$

Interpretation:

- The student's average power output during stair climbing is approximately 125 watts.
- For context, a typical human at rest produces about 50 watts, while vigorous activity can generate 400–600 watts transiently.

Biomechanical Analysis of Climbing Stairs

Muscular Actions Involved

- Quadriceps: Extending the knee to lift the body upward.
- Gluteal muscles: Hip extension providing stability and propulsion.
- Calf muscles: Push-off during the ascent.
- Core muscles: Maintain balance and posture.

Energy Distribution and Muscle Work

- The work involves concentric contractions of leg muscles.
- Energy is also spent maintaining balance and overcoming inertia.
- Muscular efficiency varies with fitness level, technique, and fatigue.

Importance of Technique

- Proper technique reduces unnecessary energy expenditure.
- Using handrails can assist, reducing muscular effort.
- Stride length optimization can make climbing more efficient.

Additional Considerations and Implications

Physiological Benefits and Risks

- Cardiovascular exercise: Climbing stairs is an excellent aerobic activity.
- Muscular strength: Enhances lower limb muscles.
- Health benefits: Improves endurance, reduces risk of cardiovascular disease.
- Risks: Overexertion, joint stress, especially if pre-existing conditions exist.

Environmental and Contextual Factors

- Stair design: Width, step height, and surface condition influence effort.
- Altitude: Higher altitudes reduce oxygen availability, affecting energy production.
- Clothing and footwear: Impact energy efficiency and comfort.

Energy Expenditure in Broader Context

- Regular stair climbing contributes significantly to daily calorie burn.
- For individuals seeking weight management, incorporating stair activity can be beneficial.
- Understanding the physics helps in optimizing exercise routines for efficiency and safety.

Conclusion

Climbing stairs may seem trivial but encapsulates fundamental physics principles like work, energy, and power. For a 75 kg student ascending approximately 50 feet, the mechanical work done against gravity is roughly 11.2 kJ, translating to an energy expenditure of about 56 kJ when accounting for physiological inefficiencies. This activity, performed over roughly 1.5 minutes, involves an average power output of approximately 125 watts, comparable to moderate physical exertion.

Beyond pure physics, this activity underscores the importance of biomechanics, muscle efficiency, and physiological adaptation. It illustrates how everyday actions are governed by energy transformations and physics principles, bridging the gap between theoretical concepts and real-world applications. Understanding these details can motivate more conscious physical activity choices and foster appreciation for the complex interplay of forces involved in routine tasks like stair climbing.

References & Further Reading:

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