

Potential energy: gravitational (mgh), elastic ($\frac{1}{2}kx^2$) and the energy stores

Potential energy is stored energy, from position, shape or state, in joules. Gravitational: $E_p = mgh$ (kg, 9.8 N/kg, m). Elastic: $E_e = \frac{1}{2}kx^2$ (k in N/m, x the extension in m from the natural length). Only the change in height matters, and the path does not.

Formula	Symbols	Notes
$E_p = m \times g \times h$	m kg; g 9.8 N/kg (10 in many papers; Moon 1.6, Mars 3.7); h metres gained	zero level is your choice; ramp or stairs give the same mgh
$E_e = \frac{1}{2}kx^2$	k spring constant N/m; x extension m	double the stretch, four times the energy; valid to the limit of proportionality
$E_k = \frac{1}{2}mv^2$	m kg; v m/s	the partner formula for conservation
$mgh = \frac{1}{2}mv^2$	so $v = \sqrt{2gh}$	speed after a fall from height h, any mass

The stores

Kind	Stored in	Example
Gravitational	height in a gravitational field	raised hammer, water behind a dam, coaster at the top
Elastic	a stretched or compressed object	spring, bow, trampoline, catapult
Chemical	bonds between atoms	food, petrol, wood, a battery
Electrostatic	charges held apart	capacitor, storm cloud, static on a balloon
Nuclear	forces in the nucleus	uranium in a reactor, hydrogen in the Sun
Magnetic	magnets held apart or together	two magnets

GCSE language: energy is transferred between stores (gravitational, elastic, chemical, kinetic, thermal, magnetic, electrostatic, nuclear) mechanically, electrically, by heating or by radiation. Lifting a book: 'energy is transferred mechanically from the chemical store of the muscles to the gravitational store of the book'.

Ten worked examples

Situation	Working	Answer
2 kg book lifted 1.5 m	$2 \times 9.8 \times 1.5$	29.4 J
70 kg person up 3 m of stairs	$70 \times 9.8 \times 3$	2,058 J
0.15 kg apple falling 4 m	$0.15 \times 9.8 \times 4$	5.9 J released
250 kg of water falling 30 m each second	$250 \times 9.8 \times 30$	73,500 J/s = 73.5 kW
Spring $k = 400$ N/m compressed 0.05 m	$\frac{1}{2} \times 400 \times 0.05^2$	0.5 J
Band $k = 80$ N/m stretched 0.25 m	$\frac{1}{2} \times 80 \times 0.25^2$	2.5 J
Trampoline $k = 6,000$ N/m pushed 0.3 m	$\frac{1}{2} \times 6,000 \times 0.09$	270 J
1 kg brick 10 m up on the Moon	$1 \times 1.6 \times 10$	16 J (98 J on Earth)
30 kg child, 2.5 m slide, no friction: speed at bottom	$\sqrt{2 \times 9.8 \times 2.5}$	7 m/s
Ball thrown up at 14 m/s: height	$14^2 / (2 \times 9.8)$	10 m

From

sciencewithshobha.com/blog/potential-energy-what-it-is-gravitational-and-elastic-potential-energy-the-formulas-pe-mgh-and-half-k-x-squared-worked-examples-and-the-energy-store-model/ · 1-on-1 online physics, chemistry and biology, KS3 to A level, Grades 6 to 12, free 30-minute first class.

Conservation, the mistakes, the curriculum, and a practice set

Potential to kinetic and back

- [] Roller coaster, 500 kg, 40 m drop: $E_p = 196,000 \text{ J}$ at the top = E_k at the bottom, so $\frac{1}{2} \times 500 \times v^2 = 196,000$, $v = 28 \text{ m/s}$. Friction makes the next hill lower
- [] Pendulum, 0.3 kg bob raised 0.2 m: 0.588 J at each end, all kinetic at the bottom, $v = 1.98 \text{ m/s}$; the height sets the speed, not the string length or the mass
- [] Dropped ball: $mgh = \frac{1}{2}mv^2$, $v = \sqrt{2gh}$, mass cancels: from 5 m, 9.9 m/s
- [] Bouncing ball returns lower: energy to the thermal store (ball and floor warm) and to sound; never destroyed

Mistakes

- [] Grams or centimetres left unconverted (200 g, 50 cm = 0.2 kg, 0.5 m)
- [] Mass confused with weight (if the weight is given, $E_p = \text{weight} \times \text{height}$)
- [] Height measured from the wrong level; only the change matters
- [] Half or square missing in $\frac{1}{2}kx^2$; k squared instead of x; the spring's whole length used for x
- [] 'Energy lost' without saying where (thermal store, sound); 'potential becomes kinetic' for a ball on the way UP; no units

Curriculum	Where
England	KS3 stores and transfers; GCSE Energy: $E_p = mgh$, $E_e = \frac{1}{2}ke^2$, $E_k = \frac{1}{2}mv^2$, conservation, store language, spring practical
Australia	Year 8 energy; Year 10 conservation and calculations; Year 11 Physics
US NGSS	MS-PS3-2 position and potential energy; HS-PS3-1/2 calculations and conservation
CBSE	Class 9 Work and Energy (mgh, conservation); Class 11 ($\frac{1}{2}kx^2$, conservative forces)
Ontario	Grade 11 SPH3U energy and conservation

Practice

1. A 3 kg bag is lifted 1.2 m. Gravitational potential energy gained? ($g = 9.8$)
2. A 45 kg gymnast stands on a 4 m beam. Potential energy relative to the floor?
3. A spring with $k = 150 \text{ N/m}$ is stretched 8 cm. Elastic potential energy?
4. A 0.2 kg ball is dropped from 3.2 m. Speed just before landing (no air resistance)?
5. A coaster has 80,000 J of potential energy at the top and 60,000 J of kinetic energy at the bottom. Where did the rest go?
6. Describe lifting a box onto a shelf in energy-store language.

Answers

1. 35.3 J. 2. 1,764 J. 3. $\frac{1}{2} \times 150 \times 0.08^2 = 0.48 \text{ J}$. 4. $\sqrt{2 \times 9.8 \times 3.2} = 7.9 \text{ m/s}$. 5. 20,000 J to the thermal store of the track, wheels and air (friction and air resistance) and to sound. 6. Energy is transferred mechanically from the chemical store of the person's muscles to the gravitational store of the box.