



AI-AUGMENTED ENGINEERING DYNAMICS: A CONVERSATIONAL APPROACH

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Author

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OBSERVE



IDEALIZE



MODEL



SOLVE / ANALYZE



VALIDATE



REPORT

How this course thinks — every week, every problem.

By Taner Onsay, PhD

**AI-AUGMENTED ENGINEERING DYNAMICS:
A CONVERSATIONAL APPROACH**

Chapter 4 — Energy, Work and Power

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The engineering workflow you will use throughout this book

CHAPTER - 4

PART 1 · ≈ 55 MIN

When Does a Force Do Work?

A force can act on a moving object without transferring energy to it. This Part builds the quantity that decides: the work of a force.

Observe

Idealize

Model

Solve / Analyze

Validate

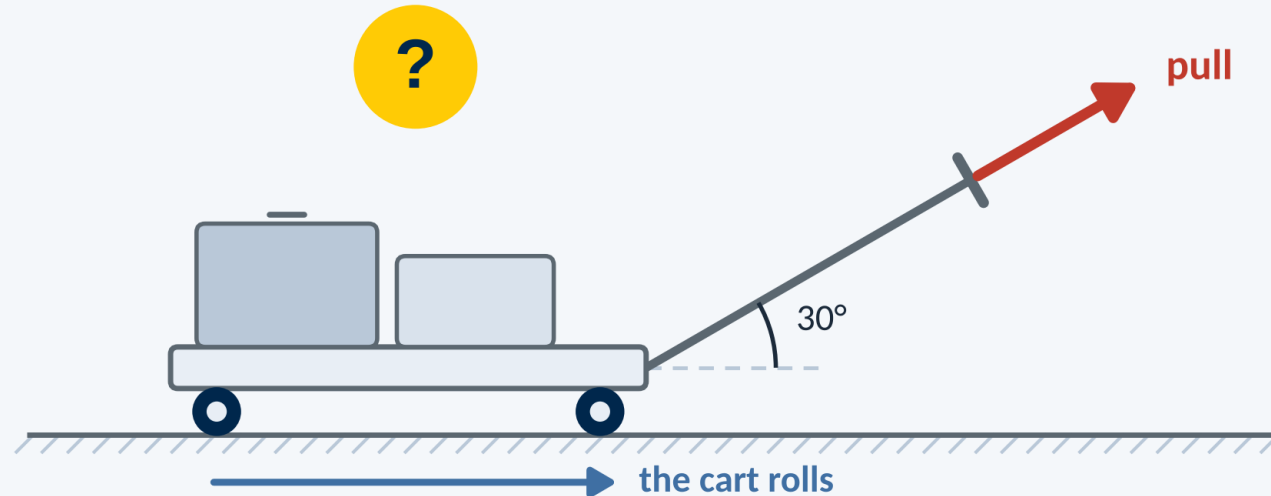
Report



Where Does the Pull Go?

BAGGAGE CART · ONE PULL

Baggage cart on a level apron



CHAPTER 3 ENDED ON THIS

“If the particle moves from point A to B, and all I want is the speed at B, do I really need the acceleration at every point in between?”

A force acts on the cart. Does that guarantee it is transferring energy to the cart — and does all of the pull count?



The engineering question for this Part

Which forces acting on a moving object actually transfer energy to it, and how much? First we need a precise way to measure that.

Observe

Idealize

Model

Solve / Analyze

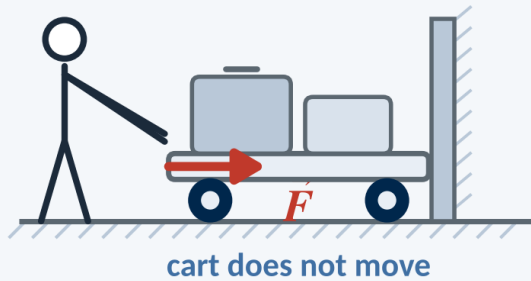
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Same Force, Different Outcomes

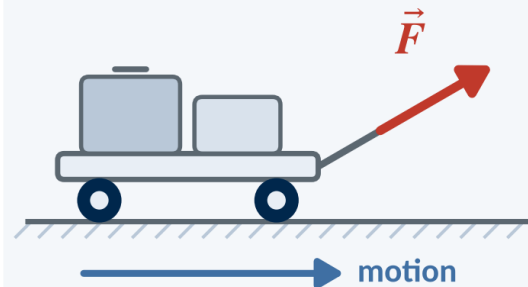
A Pushed, but blocked



Identified force:

$\vec{F}$ the hand's push on the cart

B Pulled by the handle

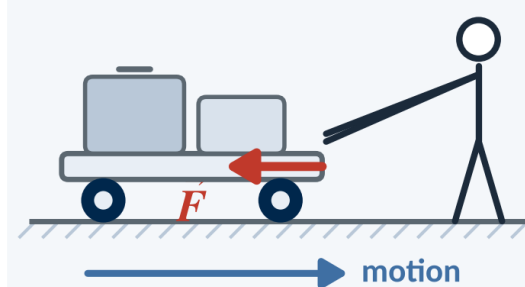


Identified force:

$\vec{F}$ = the handle's pull on the cart

C Hand on a rolling cart

cart already rolling

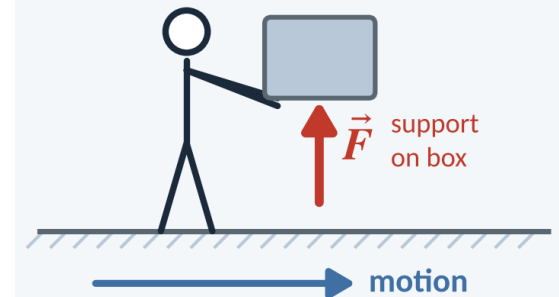


Identified force:

$\vec{F}$ = the hand's push on the rolling cart

D Carried steadily

steady walk, level floor



Identified force:

$\vec{F}$ = the upward support on the box

PREDICT

For each case: does the identified force do **positive**, **negative**, or **zero** work on the object? Vote, and write one line of reasoning.

Observe

Idealize

Model

Solve / Analyze

Validate

Report



Force Alone Is Not Enough

A 0 zero

The cart never moves, so the point where the force acts has no displacement.

B + positive

The pull has a component along the motion.

C - negative

The force points against the motion.

D 0 zero

The support is perpendicular to the motion: it holds the box up but does not push it along.

“BUT MY ARMS GET TIRED”

Muscle fibres keep contracting and relaxing, using chemical energy that ends up as heat in your body. That effort is real — but it is not work done on the cart.

Two things decide: the point where the force acts must **move**, and the force must have a component **along that motion**.

Next: which part of a force acts along the motion? Chapter 3 already answered that — for acceleration.

Observe

Idealize

Model

Solve / Analyze

Validate

Report



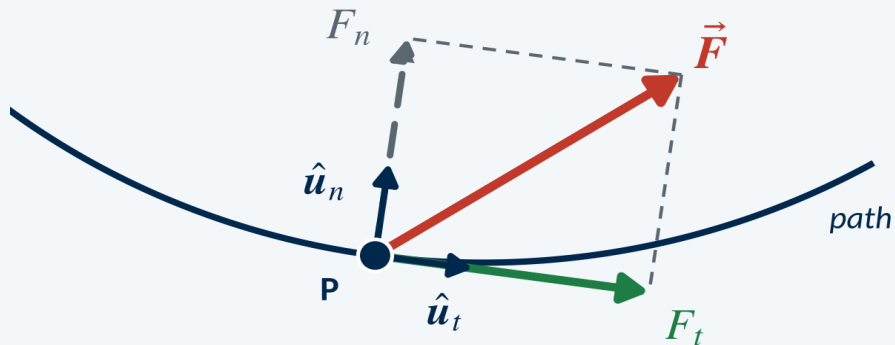
Which Force Component Changes Speed?

ONE FORCE, TWO COMPONENTS

Particle on a curved path; one force resolved

F_t along the motion

F_n across the motion



NET COMPONENTS — FROM CHAPTER 3

$$\sum F_t = ma_t \quad a_t = \dot{v}_{sp}$$

sets how fast the **speed** changes

$$\sum F_n = ma_n \quad a_n = v_{sp}^2 / \rho$$

turns the velocity: changes its **direction**



One force is not the net force

F_t of one force is only its own share; only $\sum F_t$ sets a_t . A pull can have $F_t > 0$ while the cart slows.



Why the tangential component is the one that matters for work

Only F_t (net tangential force) can change speed — so to measure what one force does along the path, count its F_t over the distance traveled.

Observe

Idealize

Model

Solve / Analyze

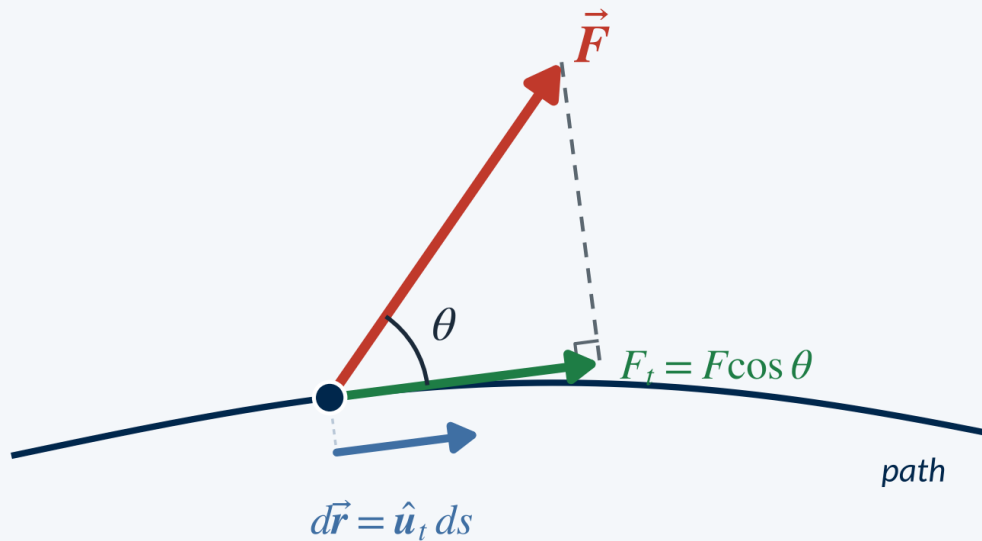
Validate

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Defining the Work of a Force

GEOMETRY AT ONE INSTANT



WORK DONE BY ONE FORCE

$$dU = \vec{F} \cdot d\vec{r} = F_t ds = F \cos \theta ds$$

$$U_{1 \rightarrow 2} = \int_1^2 \vec{F} \cdot d\vec{r} = \int_{s_1}^{s_2} F_t ds$$

ds positive path-length increment: $ds > 0$

F_t signed tangential component of this force

θ angle between $\vec{F}$ and the direction of motion, $0^\circ \leq \theta \leq 180^\circ$



A signed scalar — measured in joules

A dot product of two vectors is a number with a sign, not a direction. Unit: $1 \text{ J} = 1 \text{ N} \cdot \text{m}$.

Observe

Idealize

Model

Solve / Analyze

Validate

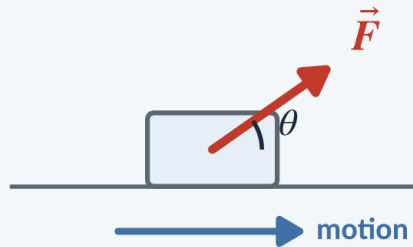
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Positive, Negative, and Zero Work

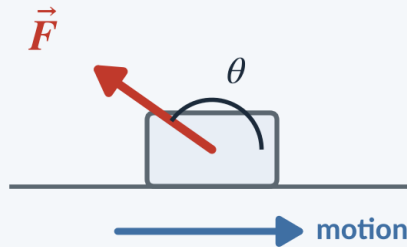
$$0^\circ \leq \theta < 90^\circ$$

positive



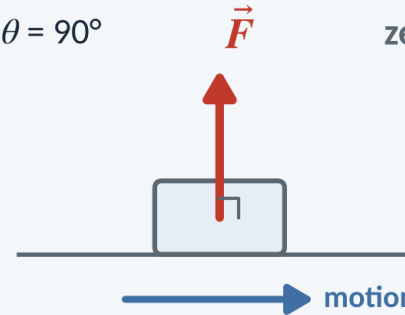
$$90^\circ < \theta \leq 180^\circ$$

negative



$$\theta = 90^\circ$$

zero



THE RULE

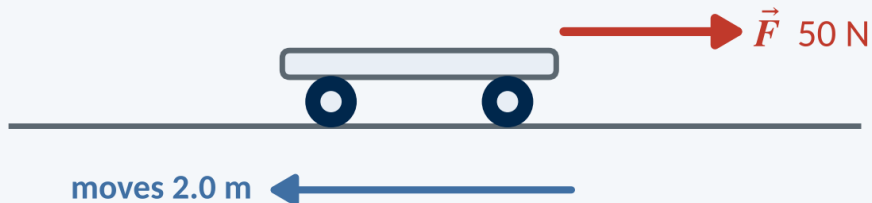
Because $ds > 0$, the sign of dU is the sign of $\cos \theta$ — the sign of F_t .

Measure θ from the direction of motion, never from an axis.

COORDINATE REVERSAL

$\longrightarrow x$ (A)

(B) $x \longleftarrow$



Axis A
+x to the right

$$U_{1 \rightarrow 2} = F_x \Delta x = (+50 \text{ N})(-2.0 \text{ m}) = -100 \text{ J}$$

Axis B
+x to the left

$$U_{1 \rightarrow 2} = F_x \Delta x = (-50 \text{ N})(+2.0 \text{ m}) = -100 \text{ J}$$

Same answer either way: the force opposes the motion. The axis is a choice; the sign of work is not.

Observe

Idealize

Model

Solve / Analyze

Validate

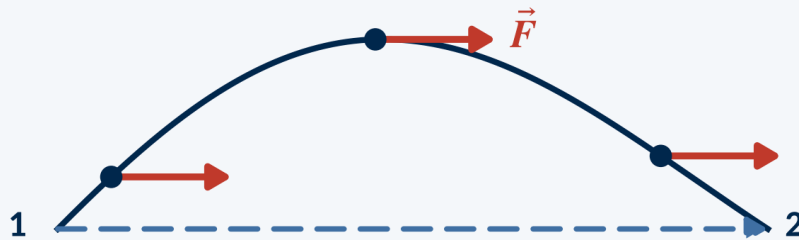
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Work by a Constant Force

CONSTANT FORCE VECTOR

same arrow everywhere: fixed magnitude and direction



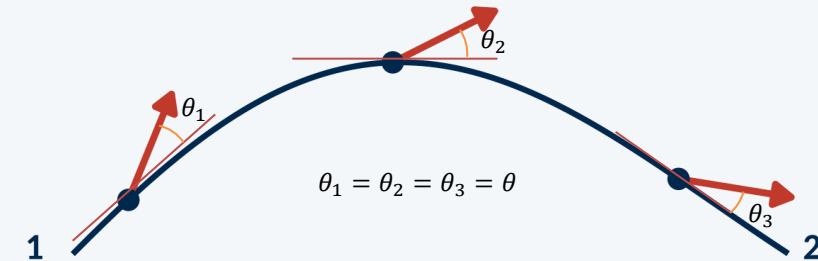
$$\Delta \vec{r} = \vec{r}_2 - \vec{r}_1$$

$$U_{1 \rightarrow 2} = \vec{F} \cdot (\vec{r}_2 - \vec{r}_1)$$

Fixed magnitude and fixed direction. Only the displacement from 1 to 2 matters, not the shape of the path between them.

CONSTANT MAGNITUDE AND CONSTANT ANGLE TO THE LOCAL TANGENT

$|\vec{F}|$ and θ fixed relative to the motion; direction turns



|work| grows with distance traveled along the path

$$U_{1 \rightarrow 2} = F \cos \theta \underbrace{(s_2 - s_1)}_{\text{arc length traveled,}}$$

Valid wherever $F \cos \theta$ is constant and the motion does not reverse; in this Part, straight paths. On a curved path this force is not a constant vector.

On a straight path traveled in one direction the two forms agree. On a curved path they do not — never swap one for the other.

Observe

Idealize

Model

Solve / Analyze

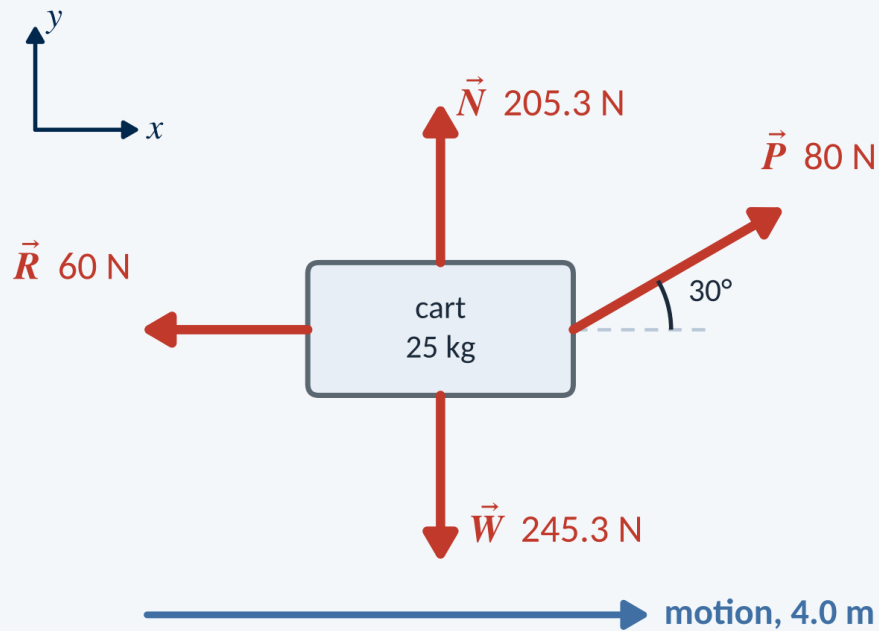
Validate

Report



Work Accounting for a Baggage Cart

FREE-BODY DIAGRAM



Net work: an algebraic sum of signed scalars.

25 kg cart on a level floor · pull $P = 80$ N at 30° above horizontal · resistance measured on a test run $R = 60$ N (illustrative value, not real data) · straight path of 4.0 m

Force	Angle θ	Work of each force = $F \cos \theta \times 4.0$ m
Pull $\vec{P}$	30°	$(80 \text{ N})(4.0 \text{ m}) \cos 30^\circ = +277.1 \text{ J}$
Resistance $\vec{R}$	180°	$(60 \text{ N})(4.0 \text{ m}) \cos 180^\circ = -240.0 \text{ J}$
Weight $\vec{W}$	90°	0 J
Normal $\vec{N}$	90°	0 J
Net work		$U_{1 \rightarrow 2}^{net} = \sum U_{1 \rightarrow 2}^i = +37.1 \text{ J}$



Contact check

$$N = mg - P \sin 30^\circ = 245.3 - 40.0 = 205.3 \text{ N} > 0 \checkmark$$



Why the mass?

Not needed for the work of $\vec{P}$. Needed to confirm $N > 0$: the cart stays on the floor.

Observe

Idealize

Model

Solve / Analyze

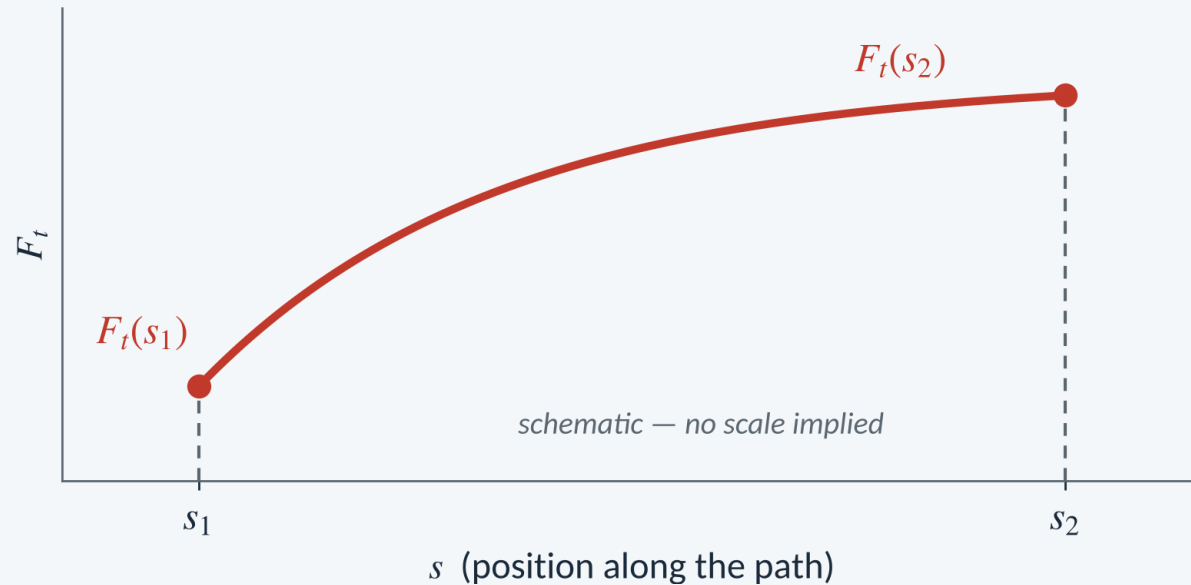
Validate

Report



What if the Force Changes?

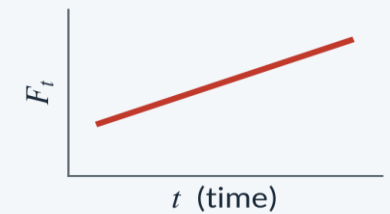
A FORCE THAT CHANGES ALONG THE PATH



PREDICT

The force grows from $F_t(s_1)$ to $F_t(s_2)$. Is one force value $\times (s_2 - s_1)$ enough? If so, which value: start, end, or the average?

Check the axis first



Vote, then write one line explaining your choice. The next slide answers.

Observe



Idealize



Model

**Solve / Analyze**

Validate



Report

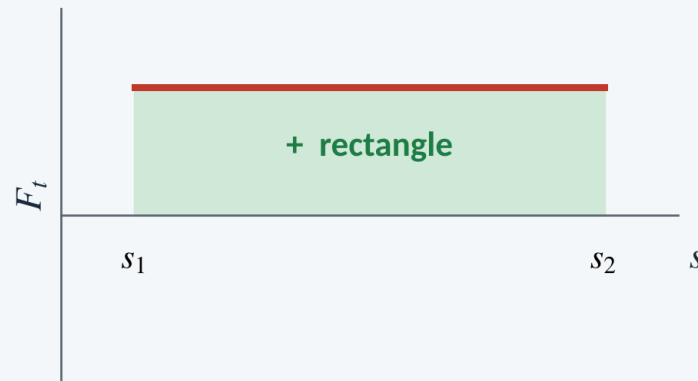


Work as Signed Area

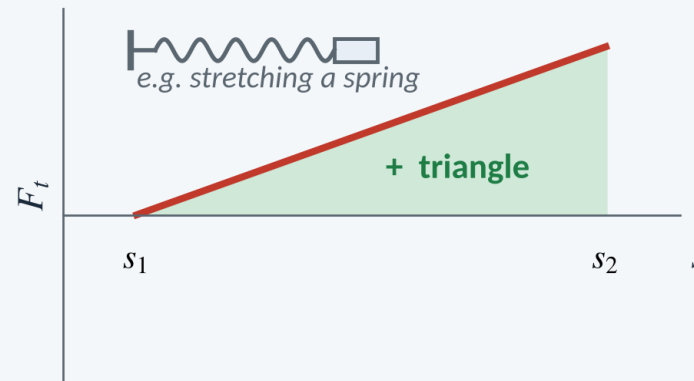
$$U_{1 \rightarrow 2} = \int_{s_1}^{s_2} F_t(s) ds$$

Add up $F_t ds$ over every small step. With $ds > 0$, s increases in the direction of motion.

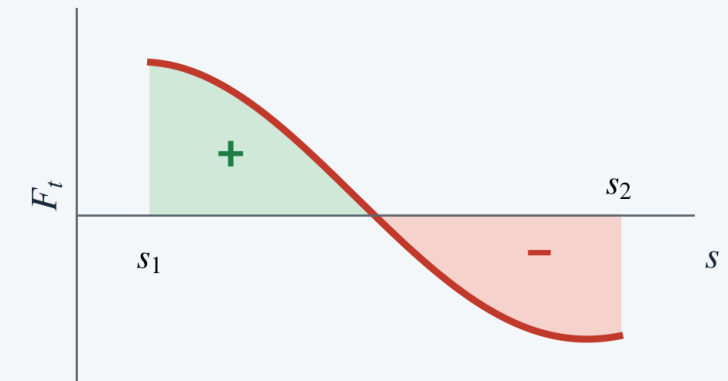
constant force



linearly changing force



force that changes sign



Signed area

Area above the s -axis adds; area below subtracts: $U = A_+ - A_-$.



Stretching a spring is one example

The pull needed grows linearly with stretch: a triangle, not one force $\times$ distance. The spring's own force opposes the stretch (Part 3).

Observe



Idealize



Model



Solve / Analyze



Validate

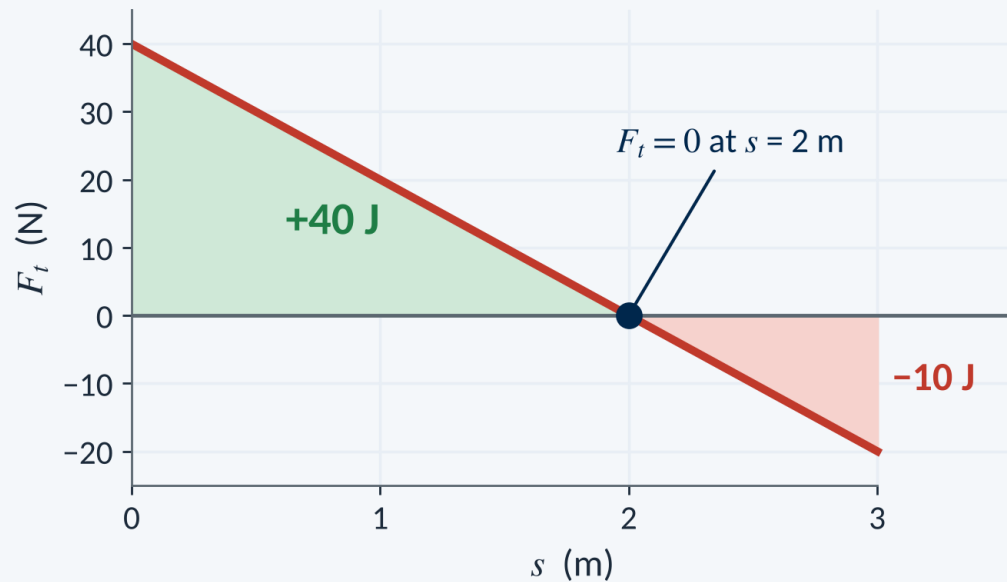


Report



Worked Example: Variable Force

THE FORCE ALONG THE PATH



$F_t(s) = 40 - 20s$ (N), s in m, $0 \leq s \leq 3$ m · illustrative values

BY INTEGRATION

$$\begin{aligned} U_{1 \rightarrow 2} &= \int_1^2 F_t ds = \int_0^3 (40 - 20s) ds \\ &= [40s - 10s^2]_0^3 \\ &= (120 - 90) J = +30 J \end{aligned}$$

BY SIGNED AREA

$$A_+ = \frac{1}{2}(2 \text{ m})(40 \text{ N}) = 40 \text{ J} \text{ (0 to 2 m)}$$

$$A_- = \frac{1}{2}(1 \text{ m})(20 \text{ N}) = 10 \text{ J} \text{ (2 to 3 m)}$$

$$U_{1 \rightarrow 2} = A_+ - A_- = 40 \text{ J} - 10 \text{ J} = +30 \text{ J}$$



Where the force reverses

$F_t = 0$ at $s = 2$ m; beyond it the force acts against the motion.



Validate

$\text{N} \times \text{m} = \text{J}$; $|U| \leq (40 \text{ N})(3 \text{ m}) = 120 \text{ J}$; both methods agree.

Observe

Idealize

Model

Solve / Analyze

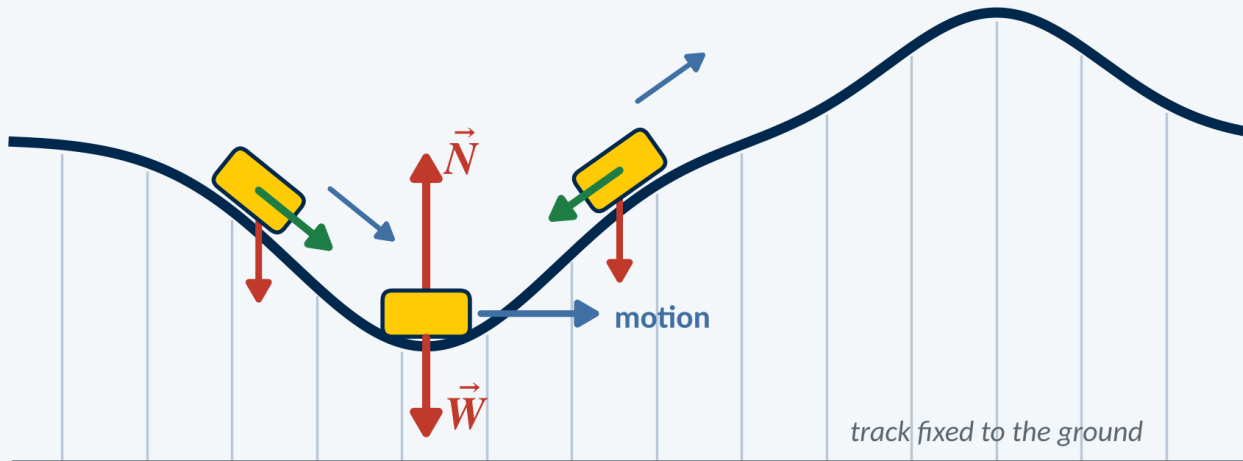
Validate

Report



Does a Normal Force Do Work?

STATIONARY CURVED TRACK



PREDICT

Does the track's normal force $\vec{N}$ do work on the car?

ON A FIXED TRACK: NO WORK

- $\vec{N}$ is perpendicular to the track, and the car moves along the track: $\vec{N} \cdot d\vec{r} = 0$ at every instant.
- $\vec{N}$ still matters: with the normal part of $\vec{W}$ it gives the net path-normal force that produces a_n . It turns the velocity; it does no work.
- “Smooth” is not the reason: smoothness only removes friction.
- the direction of the normal changes along the track



Counterexample: a moving support

A rising elevator floor pushes up on a passenger who moves up: its normal force does **positive** work.

Gravity on the same track

Green arrows: the part of $\vec{W}$ along the track — along the motion downhill (work +), against it uphill (work -).

Observe

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Can We Trust Our Calculation?

1

Dimensional consistency

$N \times m = J$; every term in a sum is in J.

2

Physical sign of work

Along the motion $\rightarrow +$; against $\rightarrow -$; across $\rightarrow 0$.

3

Coordinate-axis independence

Flip the axis: F_x and Δx both change sign; U must not.

4

Limiting-angle checks

$\vartheta = 0^\circ$: $+F \times \text{distance}$; 90° : 0; 180° : $-F \times \text{distance}$.

5

Signed-area verification

Sketch F_t versus s ; area above minus area below must match.

6

Assumptions and applicability

Straight path? Constant force? Contact kept ($N > 0$)?

PROPOSED AI SOLUTION

"The cart moves 6.0 m in the negative x-direction while the drawbar force is -300 N . Since the force is negative, the work is -1800 J ."



Your diagnosis first — 2 minutes

Which checks expose the error? Decide before anyone opens an AI tool.

THE CORRECTION

$$U_{1 \rightarrow 2} = F_x \Delta x = (-300\text{ N})(-6.0\text{ m}) = +1800\text{ J}$$

$F_x = -300\text{ N}$ is the force along x . Force and motion both point in $-x$: the drawbar acts along the motion. Checks 2 and 3 fail. Then ask an AI to critique it — and judge its critique.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



What Have We Learned?

- 1 Force alone does not guarantee work.
- 2 Work depends on the displacement of the point where the force acts.
- 3 Only the force component along the motion, F_t , does work.
- 4 Work is a signed scalar: positive, negative, or zero.
- 5 Individual works add algebraically to the net work, $U_{1 \rightarrow 2}^{\text{net}}$.
- 6 Variable-force work is a signed integral: area under F_t versus s .

CARRY FORWARD

$$dU = \vec{F} \cdot d\vec{r} = F_t ds$$

$$U_{1 \rightarrow 2}^{\text{net}} = \sum_i U_{1 \rightarrow 2}^i$$

$$ds > 0 \cdot 0^\circ \leq \theta \leq 180^\circ \cdot 1 J = 1 N \cdot m$$

Homework and self-assessment

Practise a work ledger, a signed-area graph, zero work on a curved path, and a coordinate-sign check. The Chapter 4 self-assessment tests the same ideas.

We now know how to calculate the total work done on a particle. What does that tell us about the particle's motion?

Observe



Idealize



Model



Solve / Analyze



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