Name: ____________ Date: ____________ Period: ____________

TIDES & ENERGIES OF ORBITS

Warm-Up (3 min): Earth spins. That means it has rotational KE. The Moon orbits — it has KE too. Here's the weird part: Earth is *losing* rotational KE every day, and the Moon is *gaining* orbital energy. Where is the energy going, and what's moving it?

HOW MUCH ROTATIONAL KE DOES EARTH HAVE?

WE DO Earth's Spin Energy

Model Earth as a uniform solid sphere: $I = \frac{2}{5}MR^2$. $M = 5.97 \times 10^{24}$ kg, $R = 6.37 \times 10^6$ m, $T = 24.0$ hr.

(a) Find ω in rad/s:

(b) Find I_{Earth}:

(c) Find $K_{rot} = \frac{1}{2}I\omega^2$:

Scale Check: You should get something around 2.6×10^{29} J. For comparison, the entire world uses about 6×10^{20} J of energy per year. Earth's spin contains roughly **400 million years** of humanity's total energy consumption. It's an enormous reservoir — and tides are slowly draining it.

TIDAL FRICTION: THE BRAKE PEDAL ON EARTH'S SPIN

HOW TIDES STEAL ROTATIONAL KE

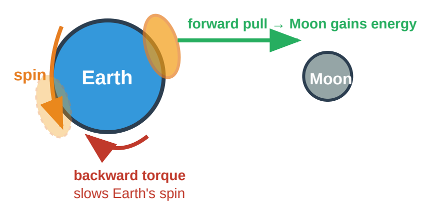
1. The Moon raises tidal bulges on Earth (ocean and rock).

2. Earth spins faster than the Moon orbits, so friction drags the bulges *ahead* of the Earth-Moon line.

3. The misaligned bulge exerts a **backward torque** on Earth's spin → ω decreases → K_{rot} decreases.

4. That same bulge pulls the Moon **forward** in its orbit, doing positive work → Moon gains energy → spirals outward.

But not ALL the lost KE goes to the Moon. Most becomes heat from tidal friction in the oceans and mantle.



Name: ____________ Date: ____________ Period: ____________

ENERGY BOOKKEEPING: TRACKING EVERY JOULE

THE ENERGY FLOW DIAGRAM

$$\underbrace{K_{\text{rot, Earth}}}_{\text{decreasing}} \xrightarrow{\text{tidal friction}} \underbrace{E_{\text{thermal}}}_{\sim 97\backslash\%} + \underbrace{K_{\text{orbital, Moon}}}_{\sim 3\backslash\%}$$

Earth's day gets 2.3 ms longer every century. That's a *tiny* fractional change in ω, but applied to Earth's enormous I, it represents a massive power drain: roughly **3.7 terawatts** — more than all the nuclear power plants on Earth combined — dissipated continuously as tidal heat.

WE DO Rate of KE Loss

Earth's day lengthens by $\Delta T = 2.3 \times 10^{-5}$ s per century. Use this to find the rate of rotational KE loss.

(a) Current $\omega = 7.27 \times 10^{-5}$ rad/s. If the day lengthens by 2.3×10^{-5} s per century, find $\Delta\omega$ per century. (Hint: $\omega = 2\pi/T$, so $\Delta\omega \approx -\omega \cdot \Delta T/T$.)

(b) Using $\Delta K_{rot} = I\omega\,\Delta\omega$, find the energy lost per century. Then divide by the number of seconds in a century to get **power** in watts.

Physics in the Wild: Tidal Heating on Io

Jupiter's moon Io is the most volcanically active body in the solar system — not because of radioactive decay, but because **tidal flexing** from Jupiter's gravity kneads Io's interior like bread dough. The "lost" rotational/orbital KE becomes thermal energy inside the moon. Same physics as Earth-Moon tides, but cranked up to 11. Io's surface is reshaped by eruptions every few years.

YOU DO Energy Accounting

The total tidal dissipation is about 3.7 TW (3.7×10^{12} W). Of this, about 3.2 TW goes to ocean heating and 0.5 TW goes to the Moon's orbit.

(a) What percentage of the lost energy becomes heat? What percentage goes to the Moon?

(b) In one year (3.15×10^{7} s), how much total energy is transferred from Earth's spin? Express in joules.

(c) A student says "tidal energy is renewable because the tides never stop." What's wrong with this claim from an energy conservation perspective?

Name: ______________________ Date: ______________________ Period: ______________________

THE ORBIT ENERGY PARADOX

FASTER ≠ MORE ENERGY

From UCM you know $v = \sqrt{GM/r}$. A satellite in a **lower** orbit moves **faster**. But to get to a **higher** orbit, you have to **add** energy (fire thrusters forward). How can adding energy make you slower?

The answer: orbital energy = KE + gravitational PE. When you go higher, you gain a LOT of PE but lose some KE. The total energy *increases* even though speed decreases. (We won't calculate PE directly — that's AP Physics C — but we can reason about it.)

WE DO The Orbital Speed-Energy Puzzle

Use $v = \sqrt{GM/r}$ with $GM_{Earth} = 3.99 \times 10^{14}$ m³/s². Compare two circular orbits:

Orbit	r (m)	v (m/s)	$K = \frac{1}{2}mv^2$ per kg
LEO (400 km altitude)	6.77×10^6		
Geostationary (35,786 km)	4.22×10^7		

(a) Which orbit has MORE kinetic energy per kilogram?

(b) Yet to reach geostationary orbit from LEO, you must *add* energy with thrusters. Explain why gaining total energy can result in less KE. (Hint: where does most of the added energy go?)

Common Misconception: "The Moon is gaining energy, so it must be speeding up." NO! The Moon is moving to a higher orbit, which means it's actually getting **slower**. Energy is increasing (more PE) but speed is decreasing. The forward pull from Earth's tidal bulge adds energy, pushing the Moon outward to a higher, slower orbit.

YOU DO Connecting It All: Angular Momentum + Energy

From the Orbits & Tides handout, you know $L_{Moon} = mvr$ and $v = \sqrt{GM/r}$, so $L_{Moon} = m\sqrt{GMr}$.

(a) If the Moon's orbital radius increases, does L_{Moon} increase or decrease? (Look at the formula.)

(b) If the Moon's orbital radius increases, does its orbital KE increase or decrease?

(c) Summarize in one sentence: As tidal friction transfers angular momentum from Earth to the Moon, the Moon moves _______ (inward/outward), gets _______ (faster/slower), gains _______ (KE/angular momentum/both), and loses _______ (KE/angular momentum/neither).

Name: ______________ Date: ______________ Period: ______________

PRACTICE & EXIT TICKET

1 Rotational KE of a Neutron Star

A neutron star (mass 2.0×10^{30} kg, radius 10 km, modeled as a solid sphere) spins at 30 rev/s.

(a) Find I and ω.

(b) Find K_{rot}. Compare to Earth's spin KE ($\approx 2.6 \times 10^{29}$ J).

(c) Neutron stars slow down over time (like Earth). What acts as the "tidal friction" for a neutron star? (Hint: they emit radiation from their magnetic poles.)

2 Classify the Energy Transfer

For each scenario, identify: (i) what loses rotational KE, (ii) where the energy goes.

Scenario	Loses K_{rot}	Energy goes to...
Brakes slow a spinning flywheel		
Earth's tides slow Earth's rotation		
Jupiter's tides flex Io's interior		
Friction brings two stacked disks to same ω		

3 KE Lost in a Rotational "Collision"

Disk A ($I = 0.40$ kg·m², $\omega = 10$ rad/s) is dropped onto stationary Disk B ($I = 0.60$ kg·m²). They reach a common ω_f.

(a) Find ω_f using angular momentum conservation.

(b) Calculate K_i and K_f. How much KE was lost?

(c) Where did the lost KE go? Why is this exactly like an inelastic collision?

Exit Ticket

A student says: "Tidal energy is free energy — we should build tidal power plants everywhere!" Evaluate this claim. In 2–3 sentences, explain where tidal energy actually comes from and what the long-term consequence of harvesting it would be.

Key Takeaway: Rotational KE is a real energy reservoir. Tidal friction is nature's brake — it converts