



Gears, Levers and Rotating Machines

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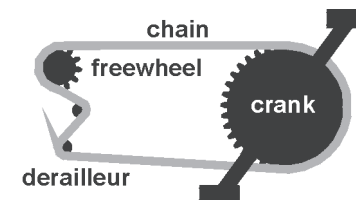
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B-4 Machines with Gears and Levers

Key question: How does a bicycle work?

In this Investigation, students explore combinations of gears and levers to help them understand how a bicycle works. They build machines using two gears and two levers, and develop a mathematical rule for making the two levers balance. After completing this activity, students should be able to calculate gear ratios on a multi-speed bicycle and to explain which gear ratios are most useful for pedaling uphill, and which gear ratios are most useful for pedaling on a level surface.



Preparation

It is helpful to bring in a multi-speed bicycle for students to examine. You may wish to ask student volunteers to bring in their own bicycles instead.

Setup and Materials

Students work in groups of four at tables.

Each group should have:

- One physics stand
- One gears and levers set
- One set of weights

Each student should have:

- Copy of the Investigation and answer sheet

The Investigation

Time  One class period

- Leading Questions**
- How do you calculate a bicycle's gear ratios?
 - How do you build machines with both gears and levers?

- Learning Goals** In this Investigation, students will:
- Build complex machines with gears and levers.
 - State the rule that relates force, distance, and number of teeth on a gear for their machines.
 - Use the skills they have gained to explain the value of multiple gears on a bicycle.

Key Vocabulary gear ratio, lever, fulcrum, balance

1

Student responses are not required for Part I.

2

(From page 2 of the Investigation)

Combinations that balance the lever				
Input axle	Teeth	36	36	36
	Weights	1	1	3
	Distance	30	30	10
Output axle	Teeth	12	24	24
	Weights	1	2	1
	Distance	10	10	20

Rule:

$$\frac{\text{weight} \times \text{distance}}{\text{teeth}} = \frac{\text{weight} \times \text{distance}}{\text{teeth}}$$

Teaching Note

Finding the rule can be tricky. You might hint that the quantity of $\text{weight} \times \text{distance}$ can be grouped together. This is consistent with what students learned about $\text{force} \times \text{distance}$ when they worked with the levers. For example, on the first input gear shown above, this quantity would be 30 w-cm, where “w” is an invented quantity corresponding to one weight. On the first output gear above, the quantity is 10 w-cm for a 12-tooth gear. On the second output gear, the quantity is 20 w-cm for a 24-tooth gear. If you point out that in the second setup, only the output gear was changed, they may notice that 10/12 is the same as 20/24 and therefore arrive at the rule.

It is interesting to note that since the distance is measured from the center of rotation and the weight acts perpendicular to the distance, the quantity of $\text{weight} \times \text{distance}$ is equal to the torque. Also, since the number of turns is inversely proportional to the number of teeth, this rule can be rewritten like this:

$$\text{torque} \times \text{turns} = \text{torque} \times \text{turns}$$

B-4

Machines with Gears and Levers



B-4

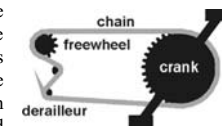
Question: How does a bicycle work?

In this Investigation, you will:

1. Explore what happens to forces that are applied through gear machines.
2. Identify a mathematical rule that predicts how to balance a machine with gears and levers.



Bicycles use gears *and* levers to enable the muscle power from your legs to turn the rear wheel. The connection between the crank and the freewheel is made with a chain so that the gear ratio can be changed while the bicycle is moving. Modern bicycles have between one and 24 different speeds. Each speed corresponds to a different gear ratio.



Why do some gear ratios on a bicycle make it easier to pedal than others? Why do some gear ratios allow you to go faster than others?

1

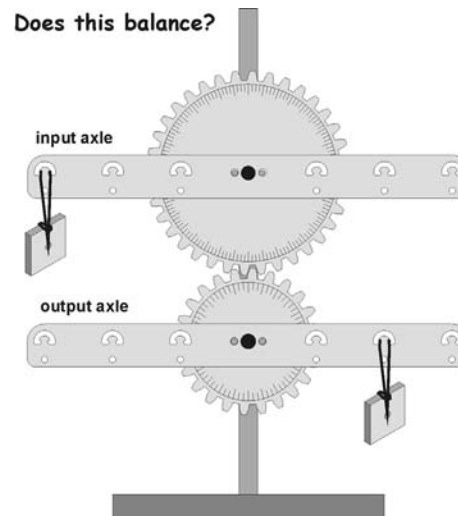
Setting up the experiment

1. You can use the long thumbscrews to attach a gear and lever to the stand on the same axle. The lever must be in the *outside* position.
2. Create machines with gears and levers like the one shown at the right.
3. Add weights to the levers. Move the weights around, and try to find the rule that makes the machine balance.

The rule must include the following variables:

- The number of weights on input and output axles,
- The distance that the weights are hung from the center of the levers, and
- The number of teeth in the gears.

Does this balance?



2 Doing the experiment



- Use the table below to write down any combinations you try that balance the levers. You can try any combinations of two gears and different arrangements of weights.

		Combinations that balance the levers						
Input axle	Teeth							
	Weights							
	Distance							
Output axle	Teeth							
	Weights							
	Distance							

- From your measurements, you should be able to find a rule that predicts when the lever will balance. The rule should relate the teeth, weight, and distance on the *input axle* to the teeth, weight, and distance on the *output axle*. Write your rule in the form of an equation, just like the gear rule.
- Challenge!** Use your rule to fill in the missing blanks in the table below. (Hint: you may need gears with numbers of teeth other than 12, 24, or 36.)

		Combinations that balance the levers						
Input axle	Teeth	24	24		12	96	12	
	Weights	4	1	1	4		3	
	Distance	30	20	10	30	10	10	
Output axle	Teeth	12		36	36	12		
	Weights		2	4		1	9	
	Distance	10	10	10	30	10	10	

3 What did you learn?

- If you were pedaling a bicycle up a hill, would you rather have a large input gear and a small output gear *or* a small input gear and a large output gear? Explain your reasoning.
- If you were trying to go farther with fewer turns of the pedals, which arrangement of input and output gears would you want on a bicycle?

Combinations that balance the levers

Input axle	Teeth	24	24	9	12	96	12
	Weights	4	1	1	4	8	3
	Distance	30	20	10	30	10	10
Output axle	Teeth	12	24	36	36	12	36
	Weights	6	2	4	12	1	9
	Distance	10	10	10	30	10	10

3

- To ride a bicycle up a hill, I would rather have a small input gear and a large output gear. Although I wouldn't go very far each time the pedals made a complete turn, it wouldn't take as much force to pedal the bike.
- If I were trying to cover a lot of distance with each turn of the pedals, I would want a large input gear and a small output gear. That way, the back wheel would make several turns each time the pedals went around once.

1. The top weight will move down. In this case, both weights are positioned to cause the machine to rotate.
2. To balance the machine, place the top weight on the left side, 30 centimeters from the fulcrum. This balances the formula:

$$\frac{\text{weight} \times \text{distance}}{\# \text{ teeth}} = \frac{\text{weight} \times \text{distance}}{\# \text{ teeth}}$$

$$\frac{2 \text{ N} \times 30 \text{ cm}}{36 \text{ teeth}} = \frac{2 \text{ N} \times 20 \text{ cm}}{24 \text{ teeth}}$$

3. The gear ratio in B will make for easier hill climbing.

In A, the gear ratio is 52:15, so the rear wheel will turn nearly 3.5 times for every turn of the pedals. In B, the gear ratio is 42:28, so the rear wheel will turn only 1.5 time for every turn of the pedals. When climbing hills, it is easier to pedal faster with less force, so the gear ratio that gives the fewest turns of the rear wheel for every turn of the pedals is preferred.

Curriculum Resource Guide: Gears and Levers

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