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University of Oregon; Spring 2025

Physics 162: Homework 5

Due date: Friday, May 2 by 11:59 pm, **via Canvas**. No late homework will be accepted, nor will homework submitted by email.

Goals: To gain practice with the physics of wind power.

First work through example #1.

Example #1. Being environmentally conscious, I decide to install small turbines under my nostrils, harnessing my inhaled or exhaled breath to generate electricity. How much power can I generate from my breath? Suppose the speed of the air is about 1 meter per second and your nostrils have a radius of 2 mm. Suppose your nostrils are spanned by ideally efficient turbine blades. The density of air is 1.2 kg/m^3 – we'll use the exact number this time.

Answer to Example #1. We figured out that the power generated by a wind turbine is

$$P = \frac{1}{2}\, \text{density}\; A\, v^3 \times \text{efficiency}$$

Here, $A = \pi R^2$, with R = 0.002 meters (converting mm to SI units, meters). The efficiency is given by the Betz limit, 0.59. Note that we have **two** nostrils, so I'll multiply by 2.

Therefore:

$$P = 2 \times \frac{1}{2} \times 1.2\,\frac{\text{kg}}{\text{m}^3} \times \pi\,(0.002)^2\,(1\ \text{m/s})^3 \times 0.59$$

$$P = 1.2 \times \pi \times (2\times10^{-3})^2 \times 1 \times 0.59$$

$$P = 1.2 \times \pi \times 4 \times 10^{-6} \times 0.59$$

I'll use a calculator for the numbers other than 10^{-6}.

$$P = 8.9 \times 10^{-6}\ \text{watts}$$

That's a **tiny** amount of power!

Make sure you can reproduce this calculation!

1 Fans, part 1. 2 pts. If you use electrical energy to turn blades and push air, you've built an electric fan – the opposite of a wind turbine. How can you calculate the power an electric fan consumes, based on its size and air speed?

A. We need to look up how much power a fan consumes; there is no way to estimate this.
B. Power is only required to slow air down, not speed it up. The power requirement of the fan is therefore zero.
C. Just like a turbine, we want to know the power associated with the kinetic energy difference between air at speed *v* and air that is still. It's just the opposite of the derivation of the wind turbine power equation we know. The equation is therefore the same.

2 Fans, part 2. (2 pts). Consider a computer fan with radius 5 cm (0.05 meters) that generates an airflow of speed 2 m/s. Suppose the fan's efficiency is 10%. (In other words, the fan consumes ten as much power as what's conveyed to the air, with the rest lost to heat, etc. This is realistic: small fans are not very efficient). How much power does the fan consume? Use the approximate value 1 kg/m^3 for the density of air. Enter the number of Watts.
Hint #1: Use SI units!
Hint #2: If you need 6W to push air, and the machine for pushing air has an efficiency of 10%, this does **not** mean you need 0.6W to push air! You'd need 60W, since only 10% of the power is going to the air. *Remember:* efficiency always means the ratio of what we want out vs what we put in.

3 Fans, part 3. (3 pts.) Your friend says, "Let's put giant fans in front of wind turbines!" The fans will increase the wind speed, so we'll have a large increase in the power the turbines generate! Why is this a terrible idea?

A. It takes energy to speed up the air. Even if the system is perfectly efficient, the energy we'd gain from the turbines will be at most equal to the energy required for the fans. In reality, since efficiency is much less than 100%, we'd gain far less energy than we put in.
B. It would be difficult to engineer a fan directly in front of a wind turbine, so the benefit in power generation will not be worth the cost.
C. The fan will increase the speed of the air, but won't change the difference in speed before and after the turbine, and therefore won't change the kinetic energy difference and the power generation.

4 Nostril power revisited. (3 pts.) Suppose I'm capturing the energy of inhaled and exhaled moving air under my nostrils for an entire year. Given the power generation from the example above, figure out how many kWh of electricity I'll generate. (Don't forget: 1 kW × 1 hour is 1 kWh!) Round your answer to the nearest power of 10, and **enter the power of 10 in Canvas.** For example: if you rounded your answer to the nearest power of 10, what would that power be? If your exact answer is 0.238, rounded to the nearest power of 10 it's 0.1, which is 10^{-1}, so the final answer you'd enter in Canvas would be **-1**.

5 Wind efficiency. (3 pts.) We've noted that the maximum possible efficiency of a wind turbine is about 60%, in other words, we convert 60% of the kinetic energy of the wind into electrical energy. What happens to the other 40%? *Hint:* Recall where the Betz limit comes from.

A. It is converted to thermal energy
B. It remains as kinetic energy
C. It is converted to gravitational potential energy, as the air rises
D. It disappears (no longer exists)

6 Shepherds Flat Wind Farm turbine power. (4 pts.) The Shepherds Flat Wind Farm in Oregon is one of the largest land-based wind farms on Earth! Many of its turbines are General Electric GE2.5XL turbines that have a radius of 50 meters and operate optimally at wind speeds of 10 m/s. The density of air is 1.2 kg/m^3 – we'll use precise numbers for all the variables in this exercise, for practice. Assume the turbine has an efficiency of 50%. What power do you expect that a turbine here generates when the wind is blowing at 10 meters per second? Enter the number of **Megawatts** in Canvas.

7 Wind turbines on Mars? (3 pts.) Suppose we wanted to build a wind turbine on Mars, to power some sort of manned outpost. Suppose some particularly windy site has wind speeds of 20 m/s (about twice the average for Mars), and we are considering installing a wind turbine there. Mars has a thin atmosphere, with density 0.02 kg/m^3. Suppose we installed the same type of turbine as in the previous problem. How much power would we expect to generate? Enter the number of **Megawatts** in Canvas.

8 US Wind Power. (3 pts.) The US is currently generating about 50 GW of power from wind, which is about 10% of our **electricity** generation. Based on these two numbers, and the population of the United States, what's the average **electrical power** consumption per person, in kiloWatts? Feel free to round the US population to the nearest 10 million. (*Hint #1:* Yes, this is a short problem. *Hint #2:* You should of course find a number that's less than the total US per capita power consumption, since electricity is just one part of our energy use.)

9 Wind power per square meter. (3 pts.) Using the equation we derived for how much wind power can be generated from some amount of land, figure out roughly how much power per square meter we'd get from a wind speed of 5 m/s (about 10 miles per hour). In other words, what's the typical power generated by one square meter of wind farm land? Enter the number of Watts in Canvas. *Suggestion:* Do this without a calculator. (*Note:* it's a small number. That's ok; one square meter is a small area!)

10 Gansu Wind Farm, part 1. (2 pts) The Gansu Wind Farm in China, also known as the Jiuquan Wind Power Base, is one of the biggest in the world, capable of generating 8 GW of power. (G = giga = 10^9.) From the Wikipedia page about it (https://en.wikipedia.org/wiki/Gansu_Wind_Farm), find out where it is, either "by eye" or by noting the coordinates. Find this location on the Global Wind

Atlas (https://globalwindatlas.info/). Roughly what are the wind speeds at that location? Pick the best option of the choices below.

About 4 m/s (9 miles per hour)
About 9 m/s (20 miles per hour)
About 20 m/s (45 miles per hour)

11 Gansu Wind Farm, part 2. (3 pts.) *Continuing:* Based on its power output and the wind speed, estimate how big the Gansu Wind Farm is. (In other words: figure out its area.) Enter the number of **square kilometers** into Canvas. (Note: there are **not** 1000 square meters in a square kilometer! How many are there?) *Hint:* Your answer should be an area larger than Manhattan, but smaller than California.