Lab #1 Answers

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Contents

Exercises on Units, Energy, and Power

Exercise 1

> This exercise asks you to calculate how many Joules of energy you can get for a dollar from different sources of energy.

Part 1(a)

> (a) A gallon of gasoline carries with it about 1.3×10^8 J of energy. Given a price of $3 per callon, how many Joules can you get for a dollar?

Put your own text and R code here to answer Exercise 1(a). Do the calculation using R and also explain what you are doing with your text, following the model of the worked example above.

```
joules_per_gal_gasoline = 1.3E8
dollars_per_gal_gasoline = 3
joules_per_dollar_gasoline = joules_per_gal_gasoline / dollars_per_gal_gasoline
```

Answer: You can get 43,000,000 Joules per dollar from gasoline.

Part 1(b)

> (b) Electricity goes for about $0.05 per kilowatt hour. A kilowatt hour is just a weird way to write Joules because a watt is a Joule per second, and a kilowatt hour is the number of Joules one would get from running 1000 W for one hour (3,600 seconds). How many Joules of electricity can you get for a dollar?

A kilowatt hour is the energy from using 1000 Watts for 1 hour, or 3,600 seconds. A Watt is 1 Joule per second, so 1 kWh = 1000 Watts × 3600 seconds.

```
joules_per_kwh = 1000 * 3600
dollars_per_kwh = 0.05
joules_per_dollar_elec = joules_per_kwh / dollars_per_kwh
```

Answer: You can get 72,000,000 Joules per dollar from electricity.

Part 1(c)

(c) A standard cubic foot of natural gas carries with it about 1.1×10^6 Joules of energy. You can get about 5×10^5 British Thermal Units (BTUs) of gas for a dollar, and there are about 1,030 BTUs in a standard cubic foot. How many Joules of energy in the form of natural gas can you get for a dollar?

```
joules_per_scf_gas = 1.1E6
btu_per_dollar = 5E5
btu_per_scf = 1030
scf_per_dollar = btu_per_dollar / btu_per_scf
joules_per_dollar_nat_gas = joules_per_scf_gas * scf_per_dollar
```

Answer: You can get 530,000,000 Joules per dollar from natural gas.

Part 1(d)

(d) A ton of coal holds about 3.2×10^{10} J of energy and costs about $40. How many Joules of energy in the form of coal can you get for a dollar?

```
joules_per_ton_coal = 3.2E10
dollars_per_ton_coal = 40
joules_per_dollar_coal = joules_per_ton_coal / dollars_per_ton_coal
```

Answer: You can get 800,000,000 Joules per dollar from coal.

Part 1(e)

(e) Corn oil costs about $0.10 per fluid ounce wholesale. A fluid ounce carries about 240 dietary Calories (which a scientist would call

```
> kilocalories).
```

A dietary Calorie is about 4200 J. How many Joules of energy in the form of corn oil can you get for a dollar?

```
calories_per_oz_oil = 240
joules_per_calorie = 4200
dollars_per_oz_oil = 0.10
joules_per_oz_oil = calories_per_oz_oil * joules_per_calorie
joules_per_dollar_oil = joules_per_oz_oil / dollars_per_oz_oil
```

Answer: You can get 10,000,000 Joules per dollar from corn oil.

Part 1(f)

(f) Now we compare the different energy sources. Rank these five energy sources from cheap to expensive. What is the range of prices per Joule?

```
dollars_per_joule_coal = 1 / joules_per_dollar_coal
dollars_per_joule_nat_gas = 1 / joules_per_dollar_nat_gas
dollars_per_joule_gasoline = 1 / joules_per_dollar_gasoline
dollars_per_joule_oil = 1 / joules_per_dollar_oil
dollars_per_joule_elec = 1 / joules_per_dollar_elec
```

Answer:

- Coal = $\$1.25\times10^{-9}$ per joule
- Natural gas = $\$1.87\times10^{-9}$ per joule
- Electricity = $\$1.39\times10^{-8}$ per joule
- Gasoline = $\$2.31\times10^{-8}$ per joule
- Corn oil = $\$9.92\times10^{-8}$ per joule

Exercise 2

In this exercise, we compare the energy it took to produce the concrete in the Hoover Dam (outside Las Vegas) to the energy the dam produces from hydroelectric generation.

Part 2(a)

The Hoover Dam produces 2×10^9 W of electricity. It is composed of 7×10^9 kg of concrete. It requires 1 MJ of energy (1 megajoule, 1,000,000 Joules) to produce each kilogram of concrete. How much energy did it take to produce the concrete for the dam?

```
kg_concrete = 7E9
joules_per_kg_concrete = 1E6
hoover_concrete_joules = kg_concrete * joules_per_kg_concrete
```

Answer: It took 7.0×10^{15} Joules to produce the concrete for the Hoover dam.

Part 2(b)

How long is the payback time for the dam to generate as much energy in electricity as it took to produce the concrete?

The electric power the dam generates is measured in Watts, which are Joules per second. If we divide the energy to produce the concrete by the power the dam produces, the result will be the number of seconds for the dam's electric generation to pay back the energy it took to produce the concrete.

```
hoover_power_watts = 2E9
hoover_payback_seconds = hoover_concrete_joules / hoover_power_watts
seconds_per_day = 24 * 3600
hoover_payback_days = hoover_payback_seconds / seconds_per_day
```

Answer: It takes 3,500,000 seconds, or 41 days, for the electricity generated by the Hoover dam to repay the energy it took to produce the concrete in the dam.

Exercise 3

It takes approximately 2.0×10^9 J of energy to manufacture 1 m^2 of crystalline-silicon photovoltaic cell. An average of 250 W/m^2 falls on the Earth. Assume that the solar cell is 18% efficient (that is, it converts 18% of the energy from sunlight into electricity). Calculate how long it would take for the solar cell to repay the energy it took to manufacture it.

```
joule_per_sq_m_pv = 2E9
i_sun = 250
efficiency = 0.18
pv_power_watts = i_sun * efficiency
pv_payback_sec = joule_per_sq_m_pv / pv_power_watts
pv_payback_days = pv_payback_sec / seconds_per_day
days_per_year = 365
pv_payback_years = pv_payback_days / days_per_year
```

Answer: It takes $4.4{\times}10^7$ seconds, or 510. days, or 1.41 years.

Exercise 4 (Grad students only)

Only graduate students are required to do this exercise.

This is one of those job-interview questions to see how creative you are, analogous to, "How many airplanes are over Chicago at any given time?" You need to make stuff up to get a rough estimate and demonstrate your ability to think creatively. The question is: *What is the efficiency of energy production from growing corn?*

Part 4(a)

(a) Assume that sunlight deposits 250 W/m^2 of energy on a corn field, averaging over the day-night cycle. There are approximately 4,200 J per dietary Calorie. How many Calories of energy are deposited on a square meter of field over the growing season?

(Note: the word "calorie" has two different meanings. Physicists and chemists, use "calorie" (with a lower-case "c") to refer to a thermodynamic unit of heat, but nutritionists use the word Calorie (with a capital 'C') to mean 1 kilocalorie (1000 thermodynamic calories). When you see "Calories" on a food label, it means kilocalories. To keep this exercise simple, I have written it so you only need to think in terms of dietary Calories.)

We have to guess at what a growing season is. From my experience growing sweet corn in a home garden, I'd estimate around 90 days.

```
i_sun = 250
joules_per_calorie = 4200
seconds_per_day = 24 * 3600
growing_season_days = 90
growing_season_seconds = growing_season_days * seconds_per_day
joules_sun_per_season = i_sun * growing_season_seconds
calories_sun_per_season = joules_sun_per_season / joules_per_calorie
```

Answer: Around $4.6{\times}10^5$ Calories of sunlight fall on each square meter of farmland over a typical growing season.

Part 4(b)

(b) Now guess how many ears of corn grow per square meter, and guess what the number of dietary Calories is that you get for eating an ear of corn. Compare the sunlight energy with the corn energy to get the efficiency.

I estimate that a corn plant is roughly circular, with a diameter of about one foot (30 centimeters) and that its leaves fill about half the area of the circle.

I estimate that a corn plant produces about 2 ears of corn on average, and that each ear has about 100 Calories of nutritional energy.

```
r_corn = 0.15 # convert cm to meters
area_corn = pi * r_corn^2 * 0.5 # this is in square meters
ears_per_plant = 2
calories_per_ear = 100
dietary_calories_per_plant =  calories_per_ear * ears_per_plant
calories_sun_per_plant = area_corn * calories_sun_per_season
efficiency = dietary_calories_per_plant / calories_sun_per_plant
```

Answer: Based on this estimate, corn plants are about 1.22% efficient at in converting solar energy into nutritional energy.

This is much smaller than the 18% efficiency of photovoltaic solar cells at converting solar energy to electricity.