1 Power from the Ocean

It has been proposed to use the thermal gradient of the ocean to drive a heat engine. Suppose that at a certain location the water temperature is 22°C at the ocean surface and 4^oC at the ocean floor.

(a) What is the maximum possible efficiency of an engine operating between these two temperatures?

(b) If the engine is to produce 1 GW of electrical power, what minimum volume of water must be processed every second? Note that the specific heat capacity of water $c_p = 4.2$ Jg^{-1}K^{-1} and the density of water is 1 g cm^{-3}, and both are roughly constant over this temperature range.

2 Power Plant on a River

At a power plant that produces 1 GW (10^9watts) of electricity, the steam turbines take in steam at a temperature of 500^oC, and the waste energy is expelled into the environment at 20^oC.

(a) What is the maximum possible efficiency of this plant?

(b) Suppose you arrange the power plant to expel its waste energy into a chilly mountain river at 15^oC. Roughly how much money can you make in a year by installing your improved hardware, if you sell the additional electricity for 10 cents per kilowatt-hour?

(c) At what rate will the plant expel waste energy into this river?

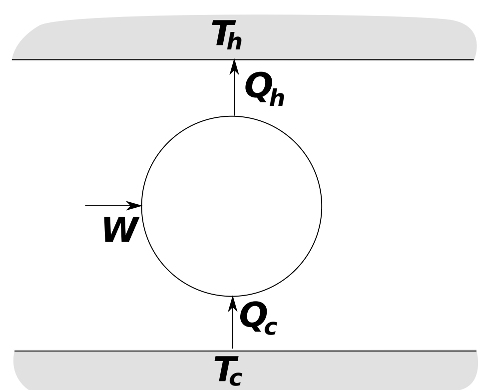
(d) Assume the river's flow rate is 100 m^3/s. By how much will the temperature of the river increase?

(e) To avoid this "thermal pollution" of the river the plant could instead be cooled by evaporation of river water. This is more expensive, but it is environmentally preferable. At what rate must the water evaporate? What fraction of the river must be evaporated?

3 Heat Pump

A heat pump is a refrigerator (or air conditioner) run backwards, so that it cools the outside air (or ground) and warms your house. We will call Q_h the amount of heat delivered to your home, and W the amount of electrical energy used by the pump.

(a) Define a coefficient of performance γ for a heat pump, which (like the efficiency of a heat engine) is the ratio of "what you get out" to "what you put in."



(b) Use the second law of thermodynamics to find an equation for the coefficient of performance of an ideal (reversible) heat pump, when the temperature *inside* the house is T_h and the temperature *outside* the house is T_c. What is the coefficent of performance in the limit as $T_c \ll T_h$?

(c) Discuss your result in the limit where the indoor and outdoor temperatures are close, i.e. $T_h - T_c \ll T_h$. Does it make sense?

(d) What is the ideal coefficient of performance of a heat pump when the indoor temperature is 70°F and the outdoor temperature is 50°F? How does it change when the outdoor temperature drops to 30°F?

4 Violating the Second Law

It is very common for people to come up with schemes and inventions that violate the Second Law of Thermodynamics. These schemes consistently fail to work, and it is valuable to learn to evaluate whether a scheme will indeed violate the Second Law. In this problem, I'm going to ask you to skim through one or more recent articles, and identify and explain *one* claim that violates the Second Law. Not every article below contains a violation of the Second Law, so you may need to read more than one article.

- "Physicists build circuit that generates clean, limitless power from graphene" (phys.org)
- "Fluctuation-induced current from freestanding graphene: towards nanoscale energy harvesting" (arxiv.org)
- "Fluctuation-induced current from freestanding graphene" (Physical Review E)

As an alternative to finding a violation in the Second Law in one of the above articles, you could find another publication violating the Second Law, and share that.

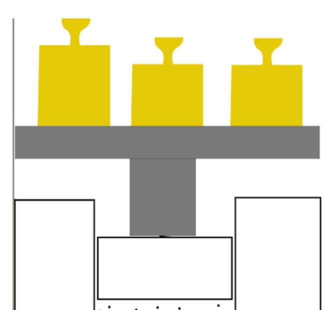
Once you have identified a violation of the Second Law, please write up a short paragraph explaining *why* it violates the Second Law of Thermodynamics, including a direct quote demonstrating the error. Sometimes it is helpful to construct a scenario in which the proposed invention or observation could be used to heat up a system that is warmer using thermal energy extracted from a system that is cooler.

Hint: papers that claim not to violate the Second Law frequently do.

5 Name the Experiment

Consider the following derivative:

$$\left(\frac{\partial U}{\partial p}\right)_{S,N} \tag{1}$$



Design an experiment to measure this derivative. In your answer, include a schematic of the aperatus and label the quantitites you would measure. Describe your measurement process, and show the algebra required to convert your directly measured quantities into the derivative.