(a) Why is the fridge running when there are frozen peas in it?
(b) How is this phenomenon related to global energy issues?

Problem 3.3: Conceptual — Thermodynamics

In principle, any sort of gradient can allow work to be done:

- Height gradient
- Pressure gradient
- Temperature gradient
- Chemical gradient

Give an example of each of these and explain, very briefly (one or two sentences), how the gradient is used to do work.

Problem 3.4: Conceptual — Systems

Identify or briefly describe an example of an open system and an example of a (mostly) closed system for each of the following categories:

(a) A physical / non-living system,
(b) A natural / ecological system,
(c) A human / social system.

Problem 3.5: Conceptual — System Boundaries

Select some form of energy, preferably **one** of the following:

- Brazilian sugar-cane ethanol
- American corn ethanol
- Coal mining
- Canadian tar sands
- Wind power
- Photovoltaics (solar cells)
- Hydroelectric (water power)
- Tidal power
- Hydrogen

For your chosen energy context, develop three system envelopes, of different size or scope, which could be used to assess the *invested* energy, as discussed in Example 3.5. For each of these three systems, you should show an explicit diagram or a detailed list showing what is / is not contained in the system, and the predominant invested and output energy flows.

Do *not* attempt to actually calculate EROEI numbers. Rather, please discuss the pros and cons of each of your systems, where the pros and cons should relate to how complete the system model is, what is omitted, and the feasibility or practicality of computing EROEI based on such a system.

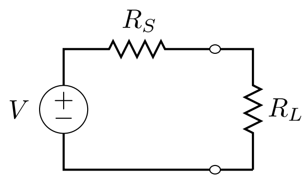
Problem 3.6: Conceptual — System Boundaries

Suppose we consider a university as a system, with a system envelope drawn around the physical campus. Draw a system diagram identifying the main energy, resource, and other physical flows (everything *except* the "flow" of people).

Problem 3.7: Analytical — Peak Power

For the given circuit, let

$$V = 1\text{Volt} \quad \text{and} \quad R_S = 1\Omega.$$



Define P_L to be the power in load resistor R_L. Draw a sketch of P_L as a function of R_L.

Do *not* mathematically solve for the peak power. However on your plot, identify the approximate location of peak usable power, peak efficiency, and peak flow.

Problem 3.8: Numerical / Computational — Population Dynamics

Example 3.4 showed some simple illustrations of population dynamics, a topic to which we shall return in Example 6.1.

The simplest possible model is that of constant reproduction rate r, such that the population p evolves over time t as

$$\dot{p}(t) = rp(t) \tag{3.8}$$

To simulate this in a computer, we need to discretize time; for a time step δ_t, we can express the discrete-time analogue to (3.8) as

$$p(n+1) = p(n) + \delta_t \cdot r \cdot p(n) \tag{3.9}$$

where sequence p needs to be initialized at the first time step:

$$p(1) = p_o$$

We need to ensure that we interpret any such simulation in the original time t, so we do *not* want to plot p as a function of n. Instead, in Matlab/Octave we would issue a plot command such as

```
plot(d_t*(1:length(p)),p)
```

Unless otherwise specified, use $p_o = 1, \delta_t = 0.1, r = 0.1$:

(a) What curve do you obtain for p?
(b) How is the curve affected by discretization? If you use other time steps $\delta_t = 0.2, 0.3$, do you see much of a change in p?
(c) How is the curve affected by the reproduction rate? How does p change for $r = 0.2, 0.3$?

Problem 3.9: Numerical / Computational — Efficiency

From (3.2) we know the limiting thermodynamic efficiency, as a function of hot and cold temperatures T_H, T_C. Throughout this chapter we assumed T_H and T_C to be *fixed*, essentially like the *static* boundary condition of Figure 3.3. However what is the efficiency of *finite* temperature reservoirs, corresponding to the *dynamic* boundary in Figure 3.3.

Let $T_H(t), T_C(t)$ represent the hot and cold temperatures over time t. We will assume the heat flow at any time to be proportional to the temperature difference

$$Q(t) = T_H(t) - T_C(t)$$

Assuming perfect efficiency, the useful work that can be performed at that time is thus

$$W(t) = Q(t)\left(1 - \frac{T_C(t)}{T_H(t)}\right)$$

leading to the differential equations

$$\dot{T}_H(t) = -Q(t) \qquad \dot{T}_C(t) = Q(t) - W(t)$$

As in Problem 3.8, or looking ahead to Section 8.3, numerically simulate these equations, given

$$\text{Time step } \delta_t = 0.01 \qquad T_H(0) = 400 \qquad T_C(0) = 300$$

(a) If we had just mixed the two reservoirs the final temperature would have been $(400+300)/2$. Why is the final temperature now different?
(b) What would the *expected* efficiency have been, for infinite reservoirs at temperatures $T_H = 400,\ T_C = 300$?
(c) What is the *actual* efficiency in your simulation, computed as

$$\frac{\int W(t)\,dt}{\int Q(t)\,dt}$$

Problem 3.10: Reading — Energy Returned on Invested

Example 3.5 discussed the concept of EROEI (energy returned on energy invested). Read[4] *Chapter 3 — Net Energy (EROEI)* in *Searching for a Miracle* [5].

Comment briefly on the challenges of net energy evaluation and the challenges associated with ambiguities of where to assert system boundaries.

[4] The chapter can be found online at the Post Carbon Institute; a link is available from the textbook reading questions page.

Problem 3.11: Policy — Accounting

Example 3.2 discussed the concept of economic accounting and system boundaries, in particular the role played by so-called *externalities* — air pollution, groundwater pollution, resource extraction, species loss.

Many ideas have been proposed, however very little has actually been accomplished, in terms of actually having these external costs recognized and acted upon.

What are the policy limitations or special interests that prevent western governments from changing their perspectives on the interpretation and calculation of GDP?

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