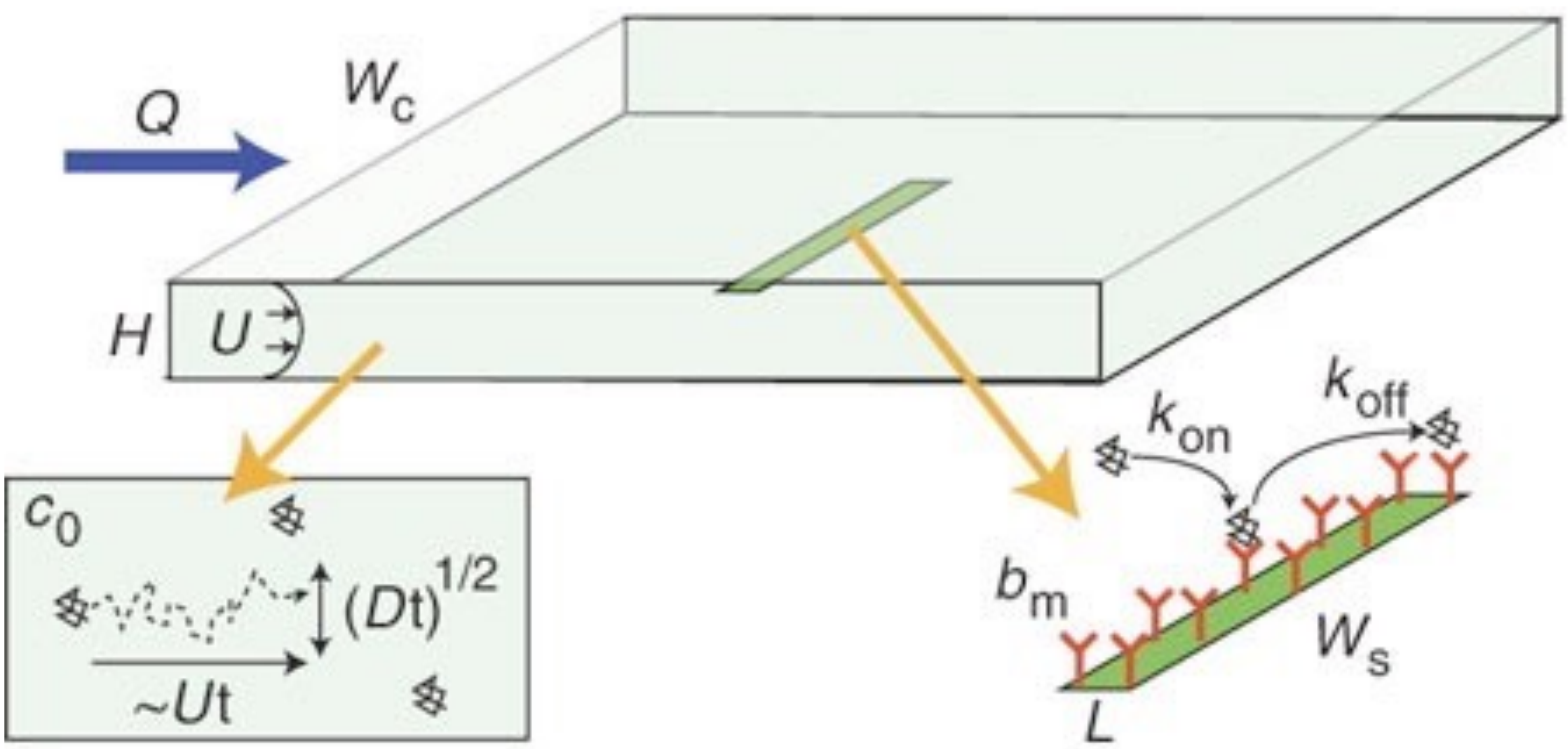
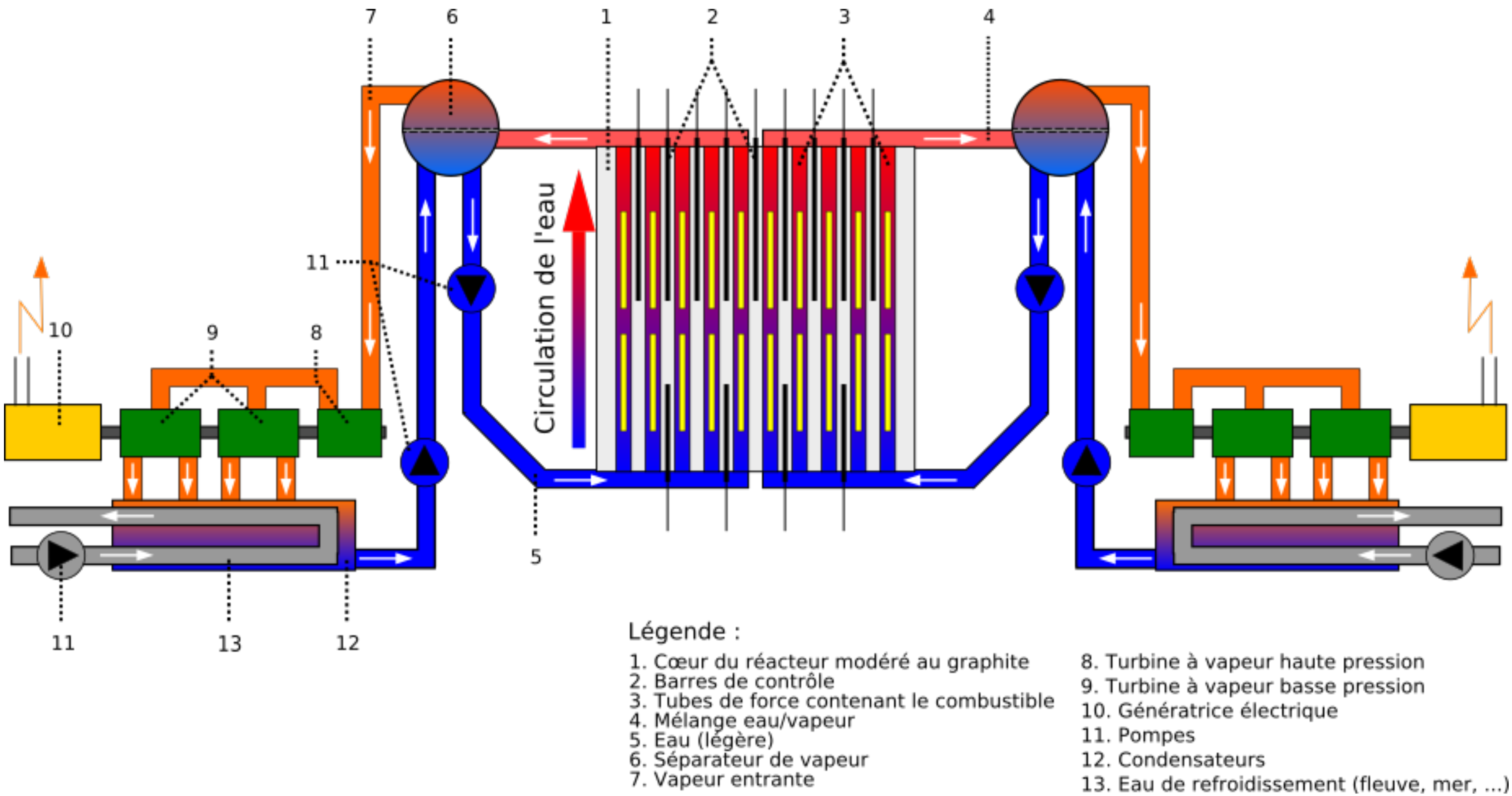
Transport phenomena

Engineering at small scale : the microchip problem

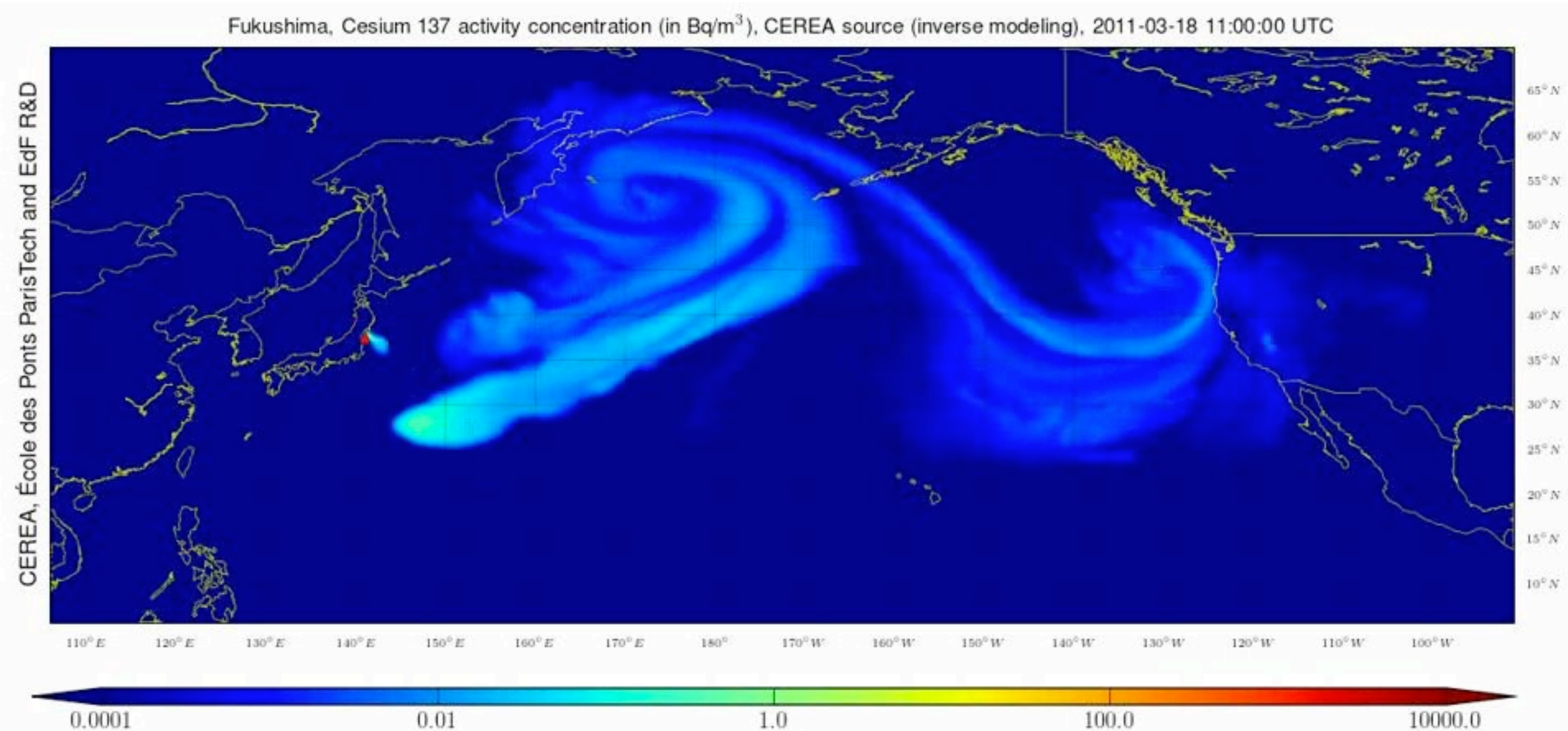


How do you design precisely a biochemical sensor on a microchip ?

Engineering at large scale : a nuclear reactor



Mass transport in the environment

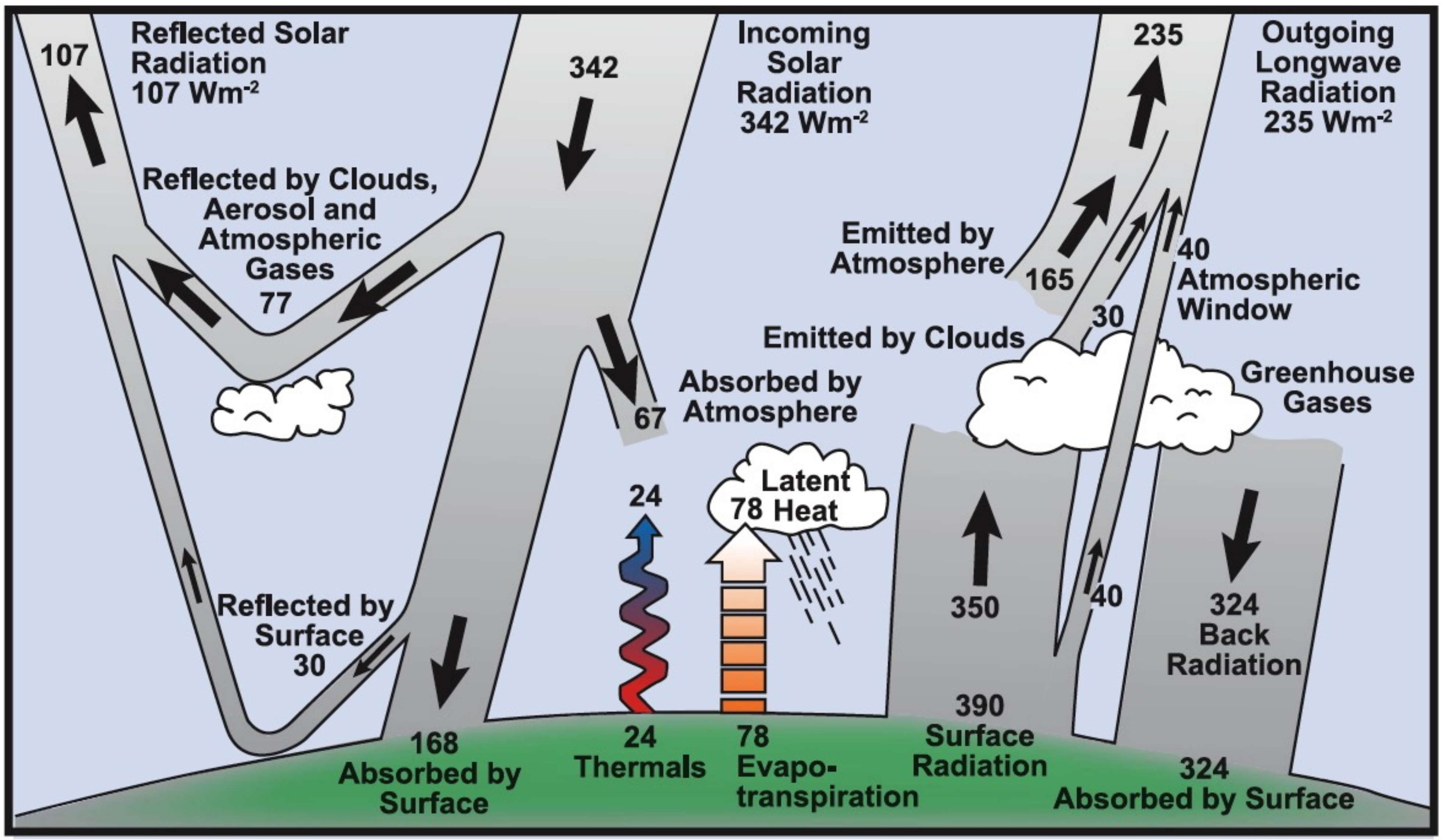


Simulation of Cs^{137} transport in the Pacific Ocean

cerea.enpc.fr/fukushima

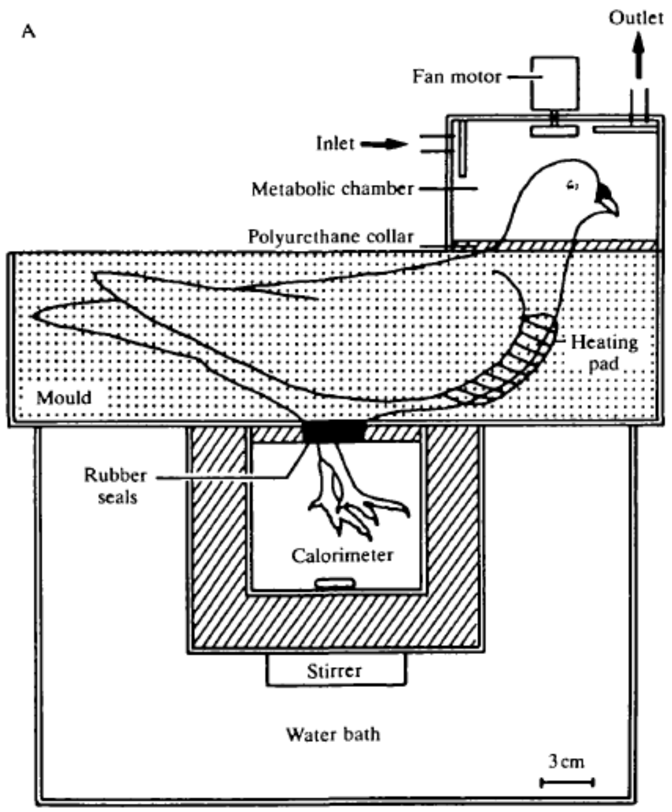
How does turbulence affects heat and mass transport ?

Heat transport in the environment : radiative equilibrium of the Earth

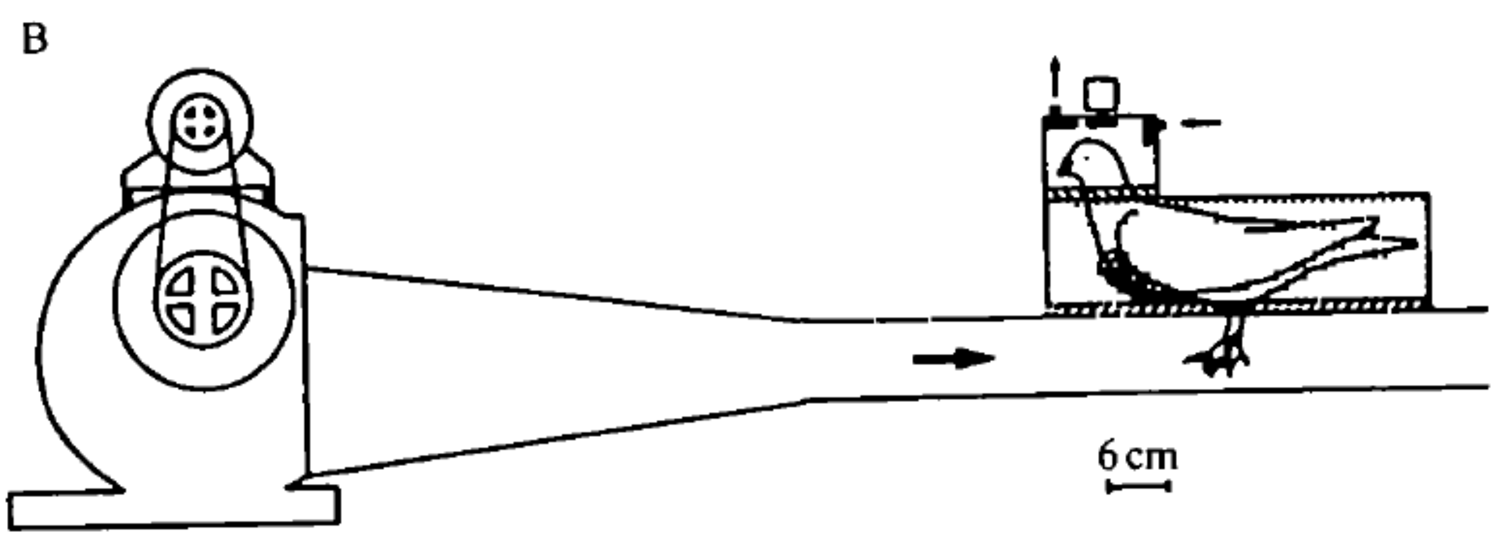


From an IPCC technical report

Heat transport in animals : thermal regulation of migratory birds



What is the cooling power of pigeon’s legs ?



L. Martineau & J. Larochelle, J. Exp. Biology 136, 193 (1988)

Heat transport in animals : thermal regulation of flying insects

The honeybee problem

T_a from 21 to 45°C

What are the different mechanisms involved in heat exchange ?
What is their relative importance ?
What is the temperature of the body as a function of air temperature ?

Outline

- review of diffusive processes
  - 1D steady state diffusion, with sources
  - geometrical effects in diffusion
- radiative heat transfer
- transfer by convection (advection)
  - combined convection and diffusion
  - transport boundary layer
- thermal convection, coupling **u** and T
- dispersion in random velocity fields (turbulent flows, porous media)

The « inverted class »

reading material is posted on :
https://blog.espci.fr/marcfermigier/transport-phenomena-2019/

you read and (hopefully) understand it

in class we check that ideas and concepts are understood through problem solving

we explain again ideas and concepts that need to be clarified

Transport processes

molecular diffusion

mass flux : Fick's law $$\mathbf{J_D} = -D\nabla C$$

heat flux : Fourier's law $$\mathbf{J_D} = -\lambda\nabla T$$

Radiative heat transfer

$$\mathbf{J_R} = \sigma T^4$$

convection
(advection by a macroscopic flow $\mathbf{u}$)

mass flux $$\mathbf{J_C} = C\mathbf{u}$$

heat flux $$\mathbf{J_C} = \rho C_p T\mathbf{u}$$

Conservation laws

local equations for concentration and temperature

rate of change = divergence (flux) + source term

$$\frac{\partial T}{\partial t} + \mathbf{u}.\nabla T = \kappa \Delta T + \frac{R}{\rho C}$$

$$\frac{\partial C}{\partial t} + \mathbf{u}.\nabla C = D \Delta C + R$$

Sources of heat and mass

chemical reactions

phase changes

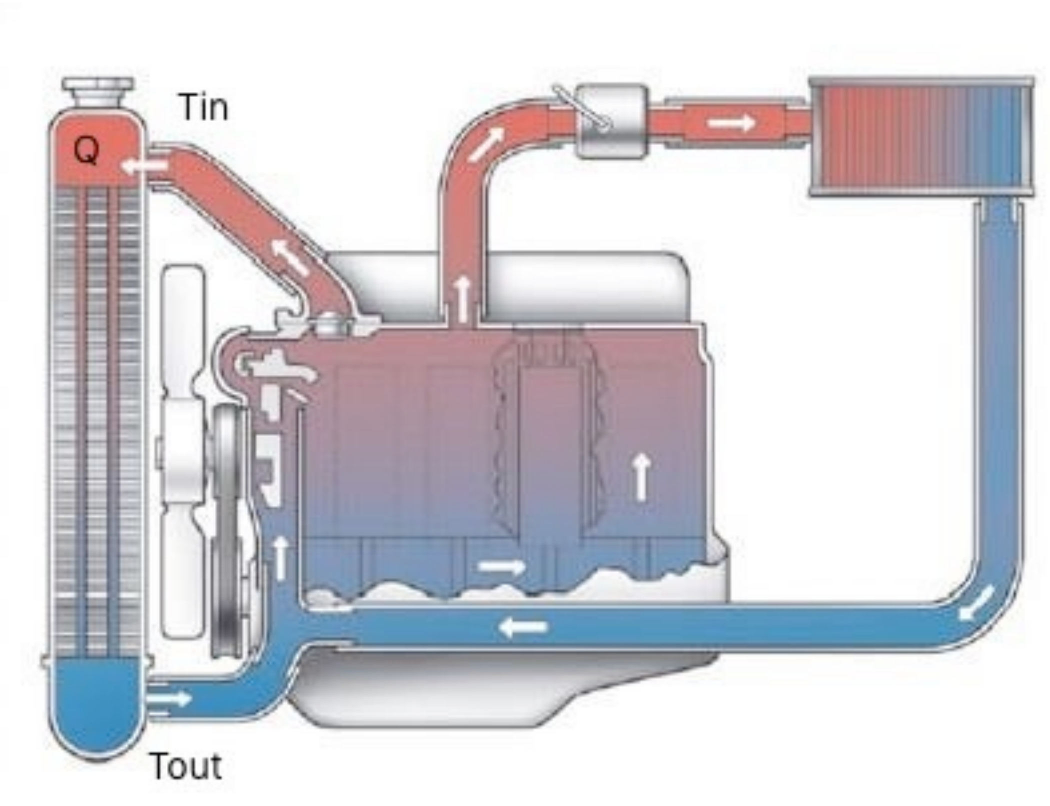
nuclear reactions

dissipative processes

convection-diffusion equations

Peclet number Pe = U L/D

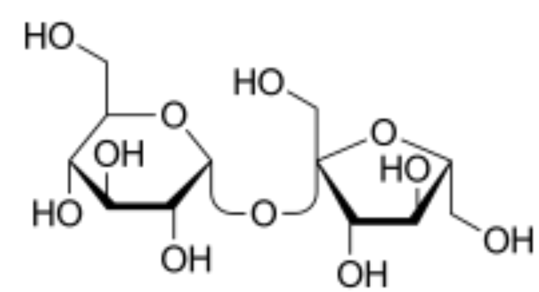
macroscopic balances



The coffee cup problem 1

If you don't stir the sugar in your coffee, why does it get cold way before it is sweetened ?

Coffee (essentially hot water) + sucrose (hydrodynamic radius 0.5 nm)



How long does it take for the sucrose to diffuse to the top ?

The coffee cup problem 2

How long does it take to cool down to room temperature ?
What if diffusion in air is the only mechanism ?

Physical properties of air :
density $\rho = 1\ kg/m^3$
specific heat $C_p = 1000\ J/kg.K$
thermal conductivity $\lambda = 0.025\ W/m.K$

Physical properties of coffee :
density $\rho = 1000\ kg/m^3$
specific heat $C_p = 4180\ J/kg.K$
thermal conductivity $\lambda = 0.6\ W/m.K$