# 1 Tea kettle

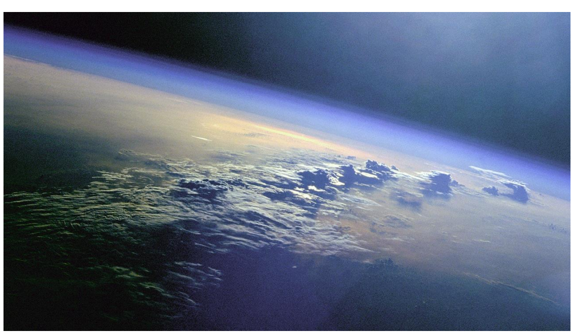
Consider the electric kettle shown in the picture. There is 1 kg of water in the kettle (4 cups of water). This electric kettle transfers energy to the water by heating. The rate of energy transfer is 1000 J/s. The specific heat capacity of water is 4.2 J/(g.K). Calculate the rate that the water temperature rises. Give your answer in units of kelvin/s.

**Note:** This is an exercise in proportional reasoning. You should not need to look up any formulas.

*Sense-making: Put it in context*—At this rate, how long would it take to heat up a kettle for making tea? Does this seem like a realistic number?

# 2 Thermal energy in the earth's atmosphere

Thermal energy is stored in all materials on Earth, including the air, water and rocks. The air is composed mostly of diatomic molecules such as $N_2$ and $O_2$.



(a) Use Google to look up the mass of the earth's atmosphere. Now, exercise some skepticism and make sure that Goggle's answer is consistent with other facts about the earth: Air pressure at sea level is about 100 kPa and the radius of the earth is about 6400 km. The air pressure at sea level (force per unit area) is caused by the downward force of gravity acting on the atmosphere directly above a unit area. The thickness of the atmosphere is much much less than the radius of the earth. Give your argument supporting or refuting the internet's value for the mass of the earth's atmosphere.

(b) We know that between 1955 and 2010, the temperature of the top 2000 meters of the ocean rose by about 0.05 C. Given this fact, assess the validity of the following statement:

> "If the same amount of heat that has gone into the top 2000 meters of the ocean between 1955-2010 had gone into the lower 10 km of the atmosphere, then the atmosphere would have warmed by about 20°C (36°F)."

Is this statement reasonable, or ridiculous? Show your calculations that support your conclusion. Your starting assumptions will include the specific heat capacity of air and water, and a reasonable guess regarding the fraction of the earth's surface that is covered with ocean.

## 3 Entropy Basics

(a) **(T3B.5)** Objects A and B have different temperatures and initial entropies of 22 J/K and 47 J/K. We bring the objects into thermal contact and allow them to come to equilibrium (the objects are isolated from everything else). What is the most quantitative statement that we can make about the combined system's entropy after the two objects come to equilibrium?

(b) **(T3B.8)** Suppose that we increase an object's internal energy 10 J by heating the object. The temperature of the object remains roughly constant at 20 C. By how much does the object's entropy increase?

## 4 Multiplicity of an ideal gas

(a) **(T3M.7)** The multiplicity of an ideal monatomic gas with $N$ atoms, internal energy $U$, and volume $V$ turns out to be roughly

$$\Omega(U, V, N) = CV^N U^{\left(\frac{3N}{2}\right)} \tag{1}$$

where $C$ is a constant that depends on $N$ alone. Use this expression, together with the fundamental definition of temperature, and they fundamental definition of entropy, to find $U$ as a function of $N$ and $T$ for an ideal gas.

(b) **(From the GRE PhysicsSubject GR0177, given in 2001)**
*Note 1*: The irreversibility of this process tells you that entropy must go (up or down?).
*Note 2*: The gas constant, $R$, is equal to Avagadro's number times $k_B$.

47. A sealed and thermally insulated container of total volume $V$ is divided into two equal volumes by an impermeable wall. The left half of the container is initially occupied by $n$ moles of an ideal gas at temperature $T$. Which of the following gives the change in entropy of the system when the wall is suddenly removed and the gas expands to fill the entire volume?

(A) $2nR \ln 2$

(B) $nR \ln 2$

(C) $\frac{1}{2}nR \ln 2$

(D) $-nR \ln 2$

(E) $-2nR \ln 2$