AOS 630: Introduction to Atmospheric and Oceanic Physics

Lecture 8   Fall 2021

The Second Law

Moist thermodynamics

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Announcements

Second Skew-T a day is due today

Remember to read the paper “Ocean temperatures chronicle the ongoing warming of Earth” for Thursday’s discussion. It’s pretty short!

In addition to the paper, we will also hold a 30 min review of what we’ve discussed up to this point. Come with questions.

Announcements

Some of the HW1 assignments uploaded were out of order. For HW2 and onward, please try to put your problems together in order in a single pdf document. That will help a lot with the grading process.

For those that want to recover credit, please add the corrected HW to Canvas and notify our grader. Canvas doesn't notify us of your uploads.

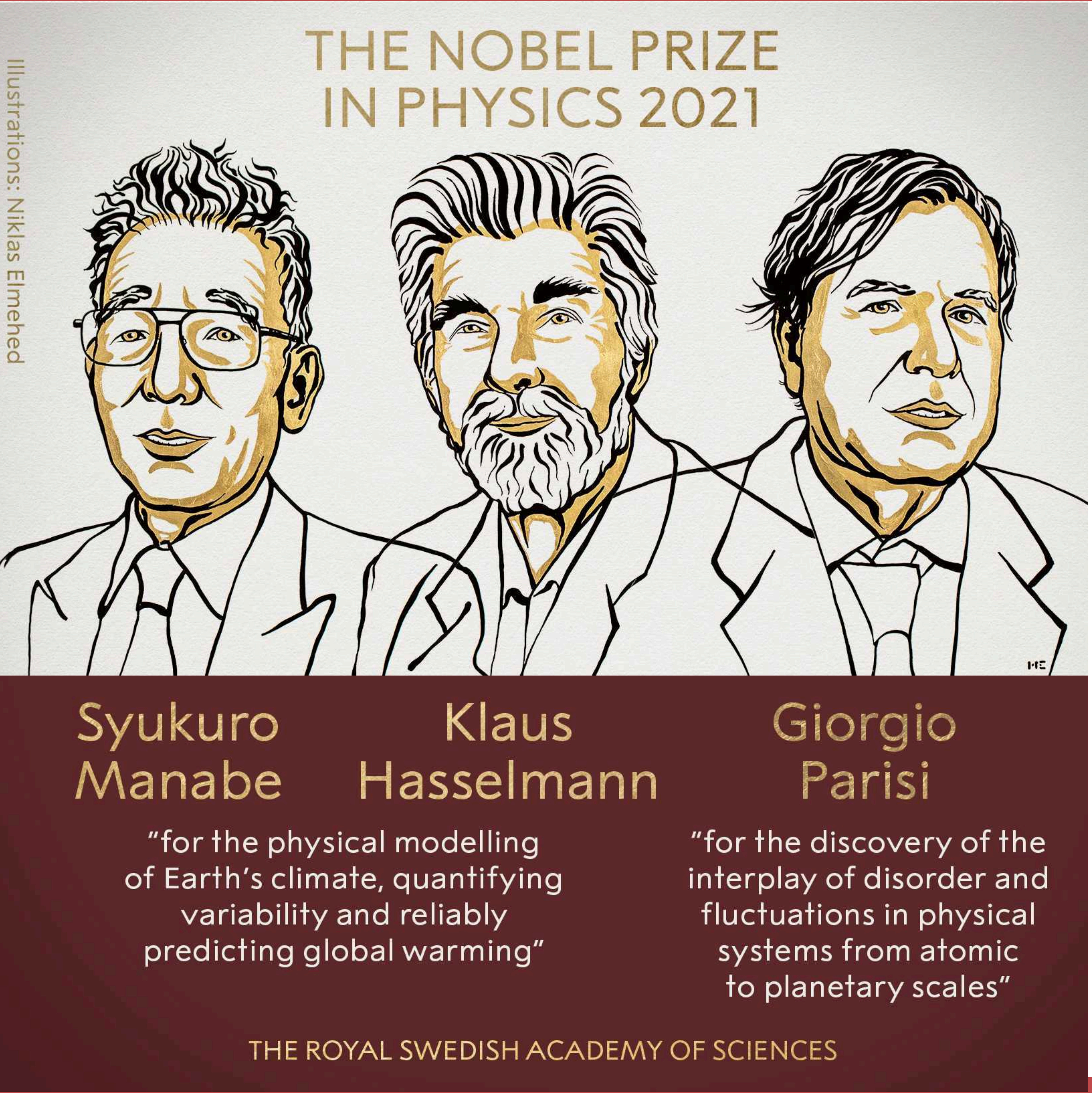
Announcements

Addendum to syllabus:

We are going to move the “Carnot Engine” discussion to the end of the moist thermodynamics part of the class in order to make it fit with a paper discussion that will happen then.

Vote on deadline for Homework

Do you prefer it being Tuesday? (This would push all HW back a lecture, the last one being due 11/23)



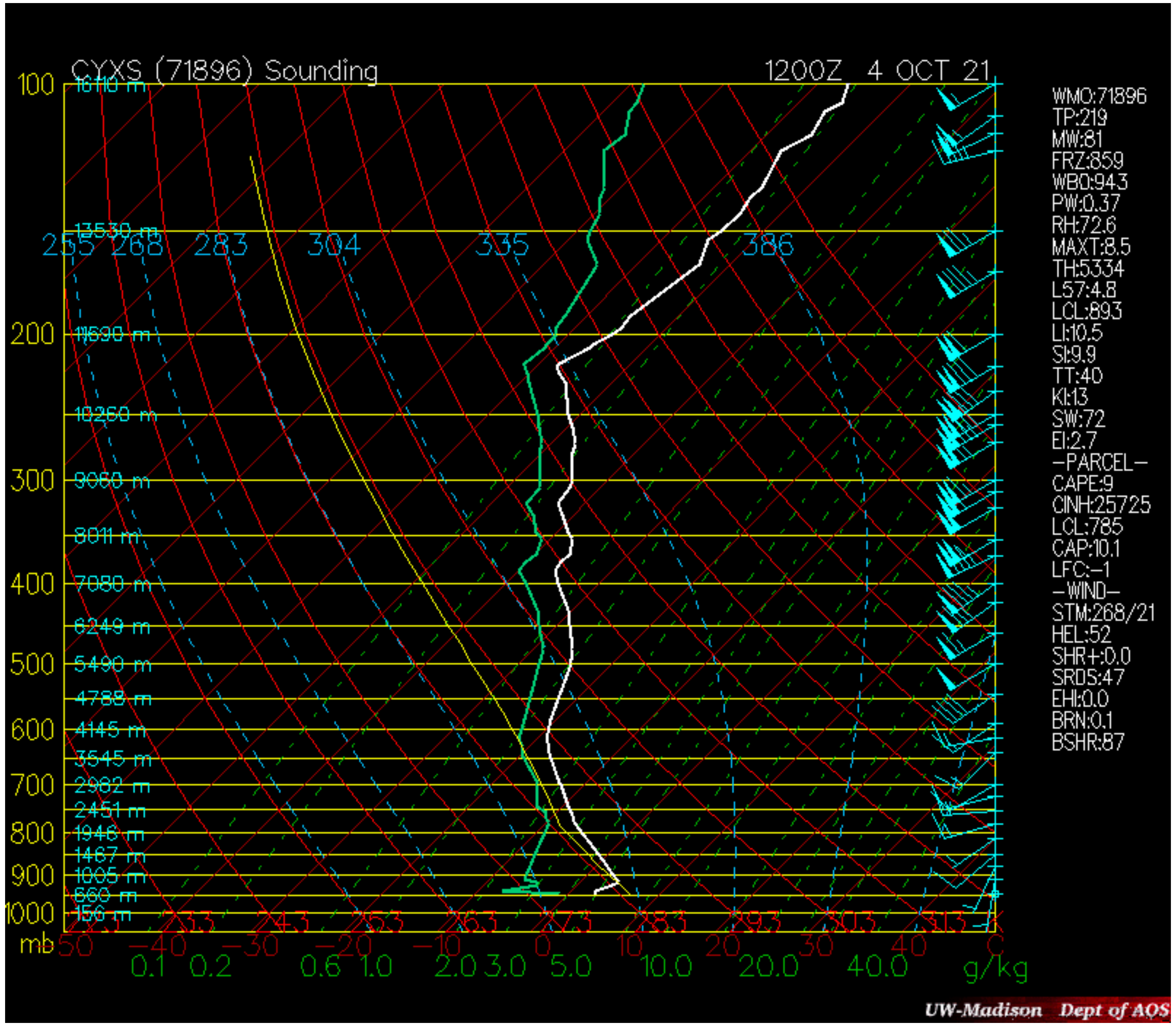
In the news:

This is the first time that climate scientists have won the Nobel Prize in Physics.

An outstanding and deserved award!

[IMO I think there should be Nobel prize for geoscience.]

Skew-T a week #3



The green dashed lines in the diagram are the mixing ratio. Examine how the values change with the axis and answer:

1. How does the mixing ratio change in the x-axis? How is it related to temperature?

2. How might your answer to (1) be related to the results of the final problem of HW1

We can define a quantity known as entropy to understand is a process is reversible or not

$$ds = \frac{\delta q}{T}$$

The word "entropy" comes from the greek word for transformation.

In reversible processes $ds = 0$

In irreversible processes $ds > 0$

Note the exact differential. **Entropy is a state variable.**

What is entropy anyway?

Entropy can be thought in terms of **multiplicity.**

Multiplicity: number of ways that you can arrange the constituents (i.e. atoms) of a system in order to get an observed large-scale state (the macro state)

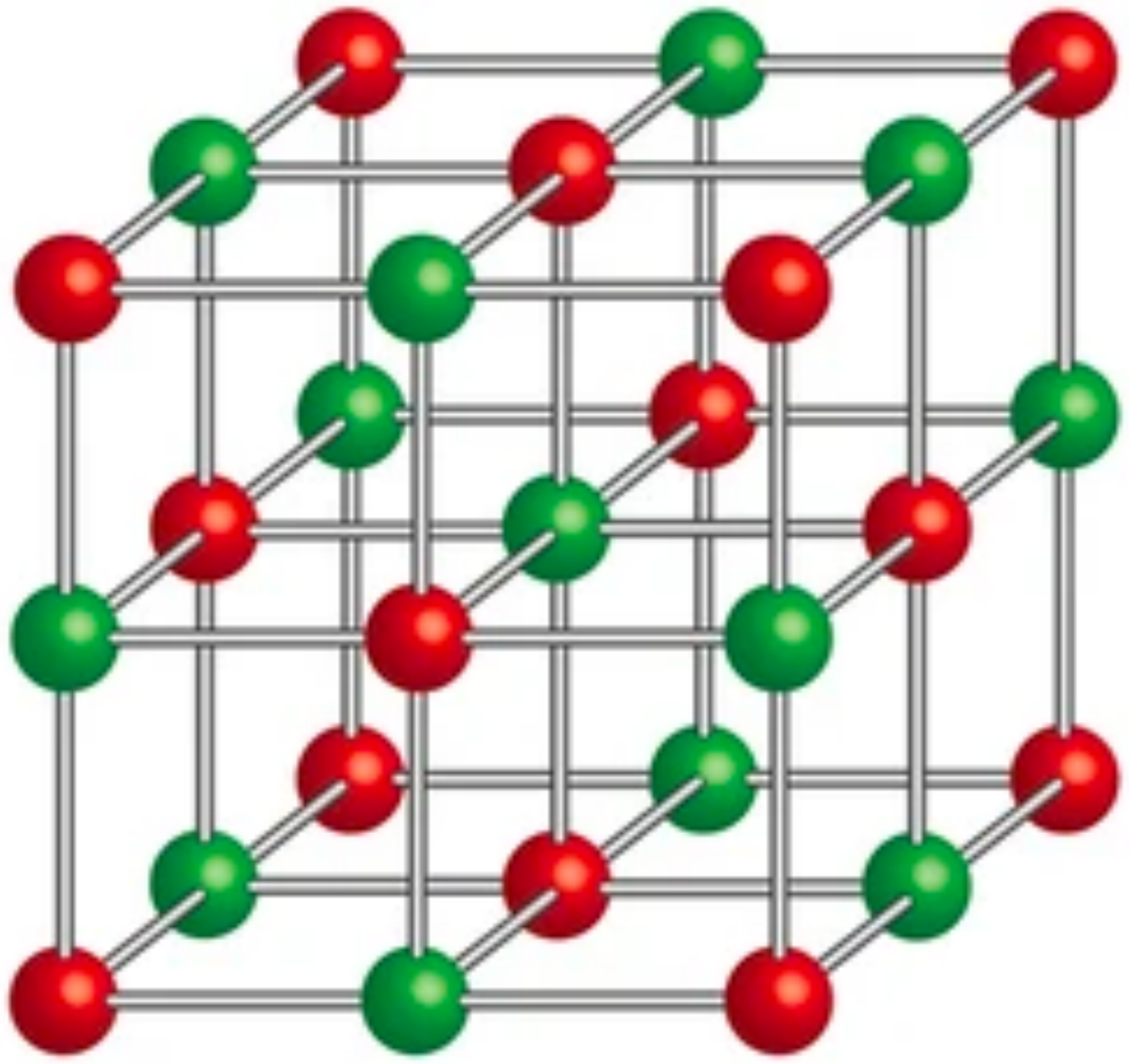
From multiplicity is where we get the expression that entropy "is a measure of disorder"

What is entropy anyway?

Low Entropy

Low Multiplicity

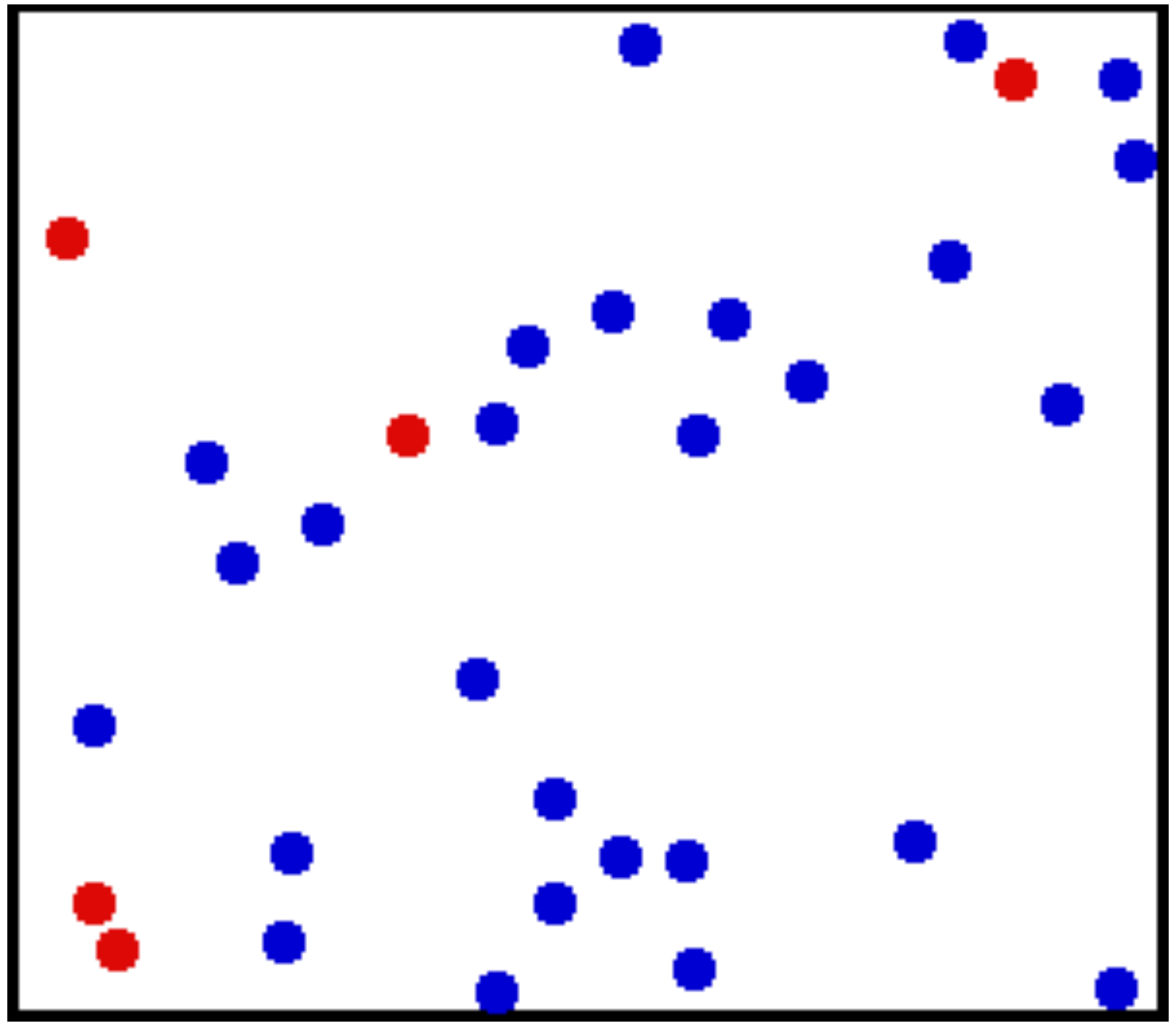
There's only a limited amount of ways in which you can rearrange the atoms in this lattice and still have a lattice



High Entropy

High Multiplicity

The molecules can rearrange themselves freely and still be a gas.



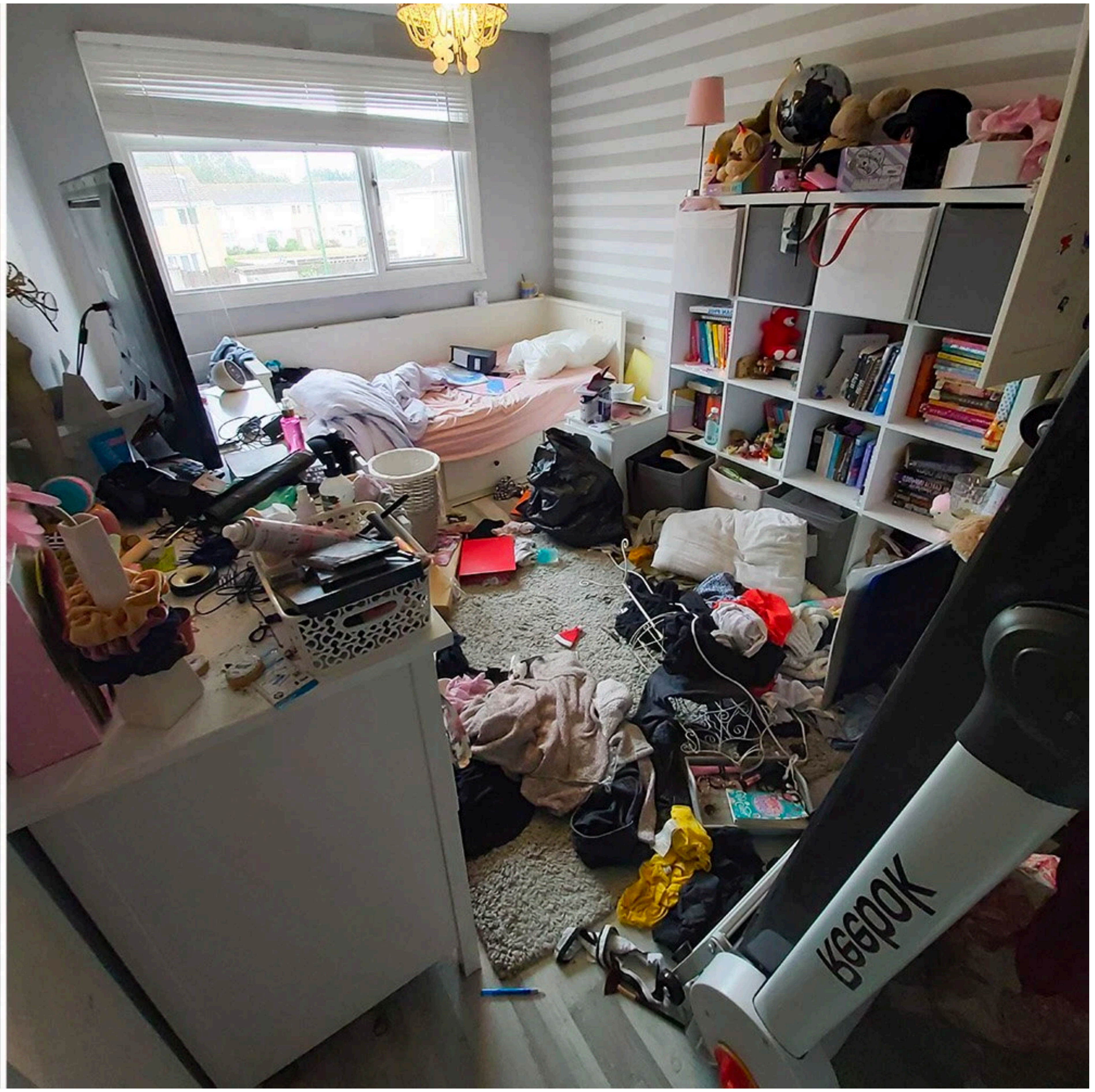
What is entropy anyway?

Low Entropy

Low Multiplicity

High Entropy

High Multiplicity



Entropy and multiplicity

Multiplicity: number of ways that you can arrange the constituents (i.e. atoms) of a system

$$\mu = \text{multiplicity}$$

$$ds = k_B d \ln \mu$$

$$k_B = \text{Boltzmann Constant}$$

$$k_B = 1.38 \times 10^{-23} \text{ J kg K}^{-1}$$

We can write the potential temperature in terms of the multiplicity:

$$c_p d \ln \theta = k_B d \ln \mu$$

Changes in potential temperature are related to changes in the multiplicity of the system.

Remark

Slow, equilibrated processes are incredibly rare. Our universe is characterized by spontaneous processes.

As a result, most processes that we observe are **irreversible.**

Entropy is always increasing.

The first law of thermodynamics

Law: Energy is conserved everywhere (system + environment)

Consequence: The change in the energy of a system is due to an exchange between it and its surrounding environment.

The second law of thermodynamics

Law: Within any system that is not in thermodynamic equilibrium with its environment entropy **must** increase. Equilibrium is achieved when entropy reaches its highest value.

Consequence: The universe we live in is constantly evolving, and thermodynamic equilibrium is rarely achieved within it. Thus ***entropy is always increasing***.

Moist thermodynamics

Suggested reading:
Petty Ch 7
Wallace and Hobbs 97-99

Up to this point

We have examined the basic thermodynamic properties of the atmosphere and ocean.

We've looked at hydrostatic balance, the equation of state, the virtual temperature correction and the first and second law of thermodynamics.

However…

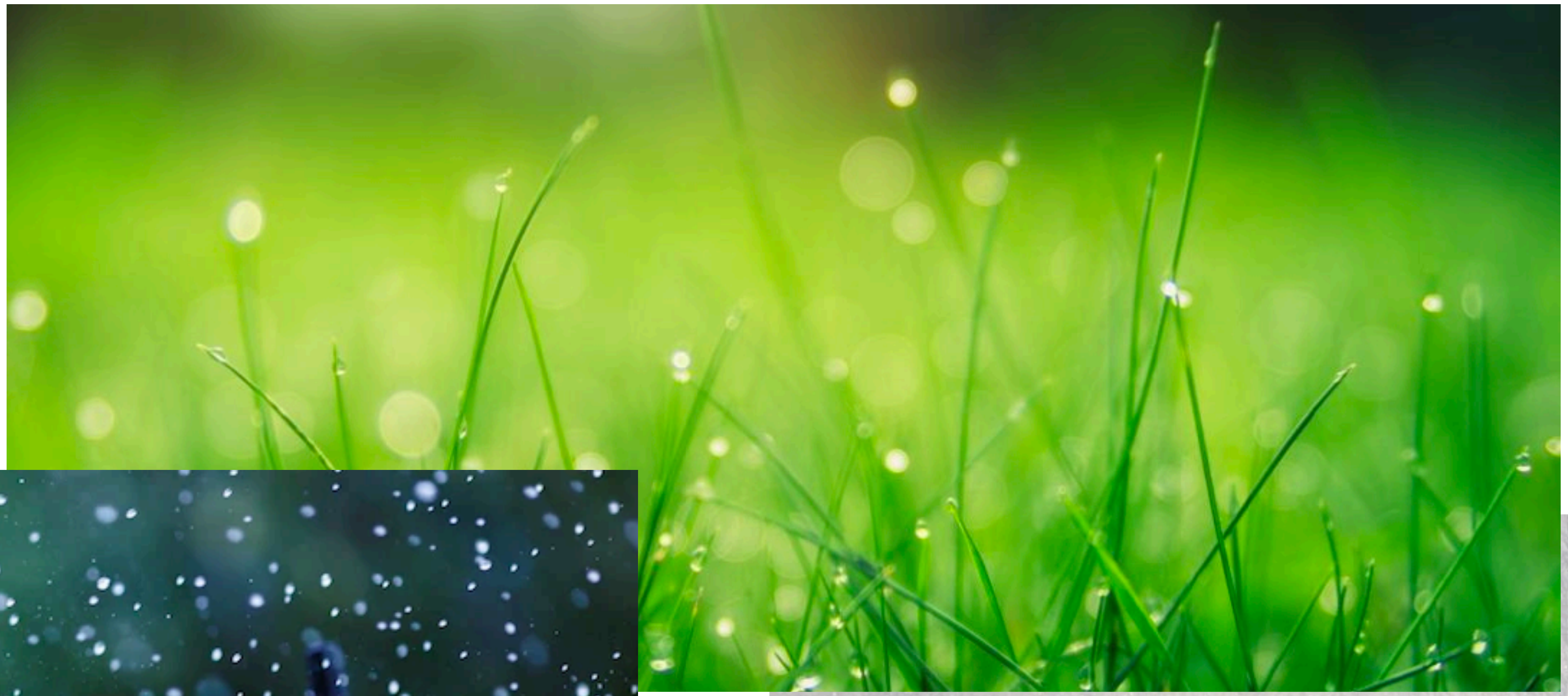
Up to this point

We haven't delved deeply into the effects of water vapor.

We know from experience that water vapor plays an important role to atmospheric processes.

Up to this point

We are specially interested **in the changes of phase of water.**



Water vapor

Water vapor is roughly an ideal gas. It follows Dalton's law of partial pressures (the total pressure is the sum of the pressure of all the constituent gases).

$$e\alpha_v = R_v T$$

The mixing ratio is the amount of water vapor mass per unit of dry air

$$r_v = \frac{M_v}{M_d}$$

The specific humidity is the amount of water vapor per unit of total air mass.

$$q_v = \frac{M_v}{M_d + M_v} \qquad q_v \simeq r_v$$

Using the ideal gas law we can express the mixing ratio and specific humidity in terms of pressure

$$e = \rho_v R_v T \qquad p = \rho R_d T_v \qquad p_d = \rho_d R_d T$$

Which are written as

$$r_v \simeq \varepsilon \frac{e}{p_d} \qquad q_v \simeq \varepsilon \frac{e}{p_d + e} \simeq \varepsilon \frac{e}{p}$$

$$\varepsilon = R_d / R_v = 0.622$$