PRESENTATION OF THE COURSE

Learn how to ask Nature a question:

Experiments, discussions and investigations

Bertrand Roehner
roehner@lpthe.jussieu.fr
http://www.lpthe.jussieu.fr/∼roehner
BNU: School of Systems Science, Yingdong Building, second floor, room 208
Home address: Institute for Theoretical and High Energy Physics
University of Paris ("Pierre and Marie Curie" campus)
Paris, France (Fa Guo)

Schedule:
Thursday, 19:50-21:30, from 9 Oct. to 27 Nov. 2014 (8 lectures),
Building 4, classroom 115

OBJECTIVE OF THE COURSE

Experiments are the basis of physics. Yet, in class-room teaching, it is usualy the mathematical framework which receives the most attention. This is perhaps because doing experiments takes much time and time is usually limited.

One should realize that without experiments the nice formulas and equations of physics would be completely meaningless. In other words, what ensures the truth of a theory is not that it is expressed with mathematical formulas or through a computer simulation but the fact that its results and forecasts agree with what is observed through appropriate experiments in the real world.

TODAY

- Presentation of the "Championship in Experimental Science".
- Mixing water and alcohol: first part of the story
- Discussion No 1 (15mn) : Survey about experimental physics
- Discussion No 2 (15 mn): Should scientific research in China entirely be published in English?

BNU CHAMPIONSHIP IN EXPERIMENTAL SCIENCE

This Championship is an initiation to research by using the method of experimental physics. 11 topics are proposed by Prof. Zhang Jiang from the "School of Systems Science" and myself. Among these 11 topics there are two subjects in physics. You will find their description in Chinese on the following website:

http://swarma.org/championship

The students (whether undergraduate or graduate) take part by groups of 2, 3 or 4. The winner-group receives a prize and a cup. There is also a second and third prize. Moreover all participants receive a gift.

In the course of your studies you will probably not have many opportunities like this one. Those who are interested can talk with me at the mid-time or at the end.

In order to register you should send an email to Prof. Zhang Jiang (zhangjiang@bnu.edu.cn).

STORY 1: MIXING WATER AND ALCOHOL

First of all, let me ask you a question which has nothing to do with physics.
Do you know what a *tautology* is?

tautology= using other words to say the same thing that was already said = to say the same thing twice but in a slightly different way.

Which one of the following translations corresponds to this meaning?

同義反覆 (文法) - 维基百科，自由的百科全书 http://zh.wikipedia.org/wiki/%E5%90%8C%E7%B...

同義反覆（文法）

维基百科，自由的百科全书

同義反覆（**tautology**[1]），又稱重言句、套套句，其意義是「把同樣內容換個方式說」。例如「剛開始的初學者」（「初學者」即有「開始」的意思）、「他們一前一後地陸續到來」（「陸續」即有「一前一後」的意思）。[2]

注釋

套套邏輯 - 维基百科，自由的百科全书 http://zh.wikipedia.org/wiki/%E5%A5%97%E5%A...

套套邏輯

维基百科，自由的百科全书

套套邏輯為英語 **tautology** 的音譯，可以指：

- 文法上的同義反覆（重言句、套套句）
- 邏輯上的恆真式（恆真句）
- 邏輯上廢話謬誤的一種

Why do I mention this word?

In a short moment we will do an experiment which consists in mixing water and ethanol (CH3CH2OH).

Then, in what follows we wish to find an *explanation* of the heat release observed in the mixing. Regarding this explanation, there is a crucial point which involves the notion of *tautology*.

Important point: Our explanation should explain not only what we have already observed but should also provide predictions for the results of experiments not yet done. For instance, we will do our experiment at room temperature that is to say around 25 degree Celsius. Perhaps the explananation will be able to predict what is changed if we make it at 5 degree or at 50 degree; or may be it will enable us to predict what happens if, instead of ethanol, we use a smaller or a bigger molecule.

If the explanation can only explain what we have already observed it will be just a tautology. Do you understand why?

The explanation has been set up in order to account for what we have observed. So, unless, we are really stupid or inept, the explanation will indeed fulfill the objective for which it was designed. If it explains nothing else it will be just another description, in other words a tautology.

This point is important because when one attends scientific conferences one sees a lot of models which are merely tautologies.

I. Water and ethanol molecules in vapor/liquid state

First, in order to get a more intuitive feeling, we wish to draw pictures representing the molecules of water (or ethanol) in vapor state or liquid state. We want the respective size of the molecules and the distances between them to be correct.

A. Physical data for water and ethanol

I recall some data that we will need.

First remember that:
1 nano-meter (nm) $= 10^{-9}$ m, 1 pico-meter (pm) $= 10^{-12}$ m, 1 Angström (A) $= 10^{-10}$ m

- Avogadro number (N)=6 $\times$ 10^{23}
- atomic masses (in g): H=1, C=12, O=16

molar mass of H2O: $m_1 = 16 + 1 + 1 = 18$g, molar mass of C2H6O: $m_2 = 46$g

- diameter of a hydrogen atom=100 pm
- bond length (in pico-m, i.e. 10^{-12} m): C-H=109, C-C=154, C-O=143, O-H=96
- From the previous bond lengths we can derive the approximate diameter of a water molecule:

$\delta_1 = 0.21$ nm
Actually, the diameter of a molecule of water as given by Internet sources is slightly higher: $\delta_1 = 0.27$nm.

Approximate length of an ethanol molecule=0.50nm
Approximate width of an ethanol molecule=0.30nm
For the sake of simplicity, we will assume that the molecule of ethanol is almost round and we will take $\delta_2 = (0.30 + 0.50)/2 = 0.40$nm as being its diameter.

- Density (in g/cubic-cm): liquid water: $\mu_1 = 1$, liquid ethanol $\mu_2 = 0.79$
- Molar heat capacity (in J/mol.K):

water (liquid) = 75, water (vapor)=36   ethanol (liquid)=112, ethanol (vapor)=78

- Heat of vaporization (kJ/mol):

water (at boiling point 100C): 41,   ethanol (at boiling point 78C): 39

B. Average distance between molecules in water and ethanol (liquid or vapor)

1 What is the volume occupied by a mole of liquid water?

2 What is the volume occupied by a molecule of liquid water?

3 What is the average distance d_1 betwen the centers of two molecules.

4 Answer the same questions for vapor water. The average distance between two vapor molecules will be denoted by D.

5 Answer the same questions for liquid ethanol and vapor ethanol. The average distance between two molecules in liquid ethanol will be denoted by d_2.

6 Draw a picture of the molecules in liquid/vapor water and in liquid/vapor ethanol. Altogether there will be 4 pictures, but the two vapor pictures are in fact identical.
It would be useful if for the next class, some of you can draw these 4 pictures in a nice way with a graphical software.

II. Potential energy of a gas and liquid

势能 - 维基百科，自由的百科全书 http://zh.wikipedia.org/wiki/%E5%8A%BF%E8%83%BD

势能
维基百科，自由的百科全书

势能（Potential Energy），亦稱位能，是儲存于一物理系统内的一种能量，是一个用来描述物体在保守力场中做功能力大小的物理量。保守力作功与路径无关，故可定义一个仅与位置有关的函数，使得保守力沿任意路径所做的功，可表达为这两点对应函数值的差，这个函数便是势能。

从物理意义上来说，势能表示了物体在特定位置上所储存的能

A. Gravitation

1 What is the potential energy E_p with respect to the Earth for a mass m at a height h above ground level?

2 Where is this potential energy equal to zero?

3 We dig a hole of depth d under the mass m. How is its potential energy changed? Where is it equal to zero? Through this question we see that the location where the potential energy is zero is somewhat arbitrary and can be chosen by convention.

4 We consider the system S comprising the mass m and the Earth. In order to lift the mass m from ground level to height h one must give the energy E_p ($E_p > 0$) to the system. Conversely, if the mass falls from height h to the ground the system will give energy to the outside.
Draw two figures which summarize these observations.

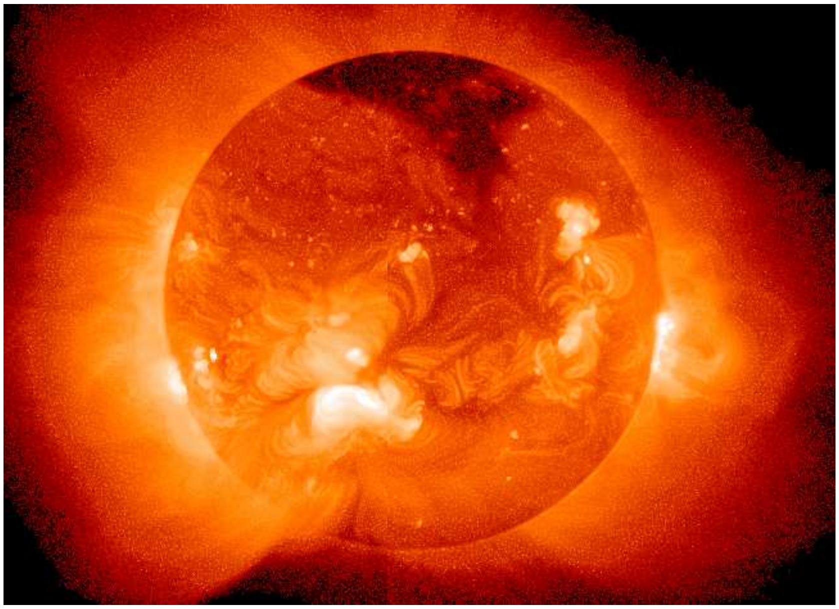
5 When the mass falls, in what form of energy is E_p dissipated?
Sketch a figure which shows the 3 forms of energy involved in this process: (i) potential energy before the mass falls, (ii) kinetic energy just before the mass hits the ground (iii) and finally the form of energy which appears when the mass hits the ground.

6 We suppose that when the mass hits the ground all its kinetic energy is transfered to the mass. For a iron mass of 1 kg falling from a height of 10m what will be its temperature increase ΔT?
The specific heat of iron is $C_p = 0.45$ kJ/kg.K.
Can this temperature increase be detected?
Actually, for a fall in air, the observed temperature increase will be slightly smaller than ΔT. Do you see why?

7 Suppose that the mass m falls not in air but in honey that is to say a fluid of high viscosity. It will fall very slowly but will this affect the amount of energy which is released? Where will the heat generated in the fall be dispersed?

8 An iron ball of 1 kg has a radius of about 3 cm. Suppose that it falls in a 10m-high cylinder of radius 4 cm filled with honey. What will be the temperature increase in the system honey+ball?
Data The density of honey is 1.4 and we will admit that its specific heat is the same as for water, i.e. $C_p = 4.1$ kJ/kg.K.
Is it possible to detect this temperature change?

9 **Application to the creation of stars.**
Do you know how stars are formed?
If you did not know, does the process considered above give you a clue?
It starts with a huge cloud of dust. Through mutual attraction the density of the dust will increase. This concentration process is accompagnied by a release of potential energy which raises the temperature of the dust until eventually nuclear reactions start to occur. This will the birth of the new star.



B. Spring or elastic wire

As a second example of potential energy we consider a mass m connected to a steady point by an horizontal elastic wire. The position of the mass when no force is applied is taken as the origin of the x axis.

1 When the mass is displaced and the length of the spring is increased by x the restoring force of the spring is supposed to be $F = -kx$. From the experiment performed earlier, can you give two factors which will change the strength k?

2 Do you know the potential function which corresponds to this force?

3 We consider the system comprising the spring and the mass. In order to stretch the spring one must give energy to the system. Conversely, when the mass and the spring return to their equilibrium position the system gives energy to the outside. As a result its own energy decreases. Draw two diagrams similar to those in question 4 which summarize these observations.

4 When the spring contracts and comes back to its initial length, some heat is generated. Where is this heat dispersed?

5 When a weight of 0.5 kg is hung on a vertical elastic wire the length of the wire increases by 10cm. What is the constant k of the elastic wire?
In horizontal position the wire is stretched so that its length increases by 1 meter. Then, it is released. What will be its temperature increase? Is this temperature change detectable?
Data The weight of the elastic wire is 100g and its specific heat is $C = 1.8$ kJ/kg.K

6 Clustering of ants

When ants are left alone after a while they form an aggregate in which they cluster together. This means that the ants are attracted to one another. We would like to compute the temperature increase in such a clustering process. As we do not know the expression of the force between them we will rather base our reasoning on their kinetic energy. We will assume that they walk at a speed of 1cm/s until they reach the aggregate where they stop suddenly. We assume their individual mass to be 1 mg. What will be the temperature increase due the aggregation?
Data: We will assume that the specific heat of ants is similar to the specific heat of celluloid (cellulose nitrate) which is around 1.3 kJ/kg.K.

C. Attraction potential between molecules

In the previous case the restoring force increased with distance. On the contrary, the force between two molecules decreases with distance. This leads us to consider an attractive force between two molecules separated by a distance x that is defined by the following formula (Van der Waals interaction):

$$F(x) = -\frac{K}{x^6} \text{ for } x > r$$

1 What is the physical meaning of r?

2 Can you write the potential function $V(x)$ corresponding to this restoring force? As we have already seen, the location where the potential vanishes can be chosen according to our wishes. We decide that the potential should vanishe when the two molecules are separated by a "large distance". Mathematically, "large" means $x \to \infty$ but in practice "large" means more than one micro-meter.

3 We denote by D the intermolecular distance of water vapor (it is the same for ethanol vapor) and by d_1 the intermolecular distance of liquid water. Draw the graph of the potential energy $V_1(x) = K_1/x^5, x > d_1$.

On this curve there are two points of special interest:

- Point $A1$ at $x = d_1$ corresponds to liquid water,
- Point B at $x = D$ corresponds to vapor water at atmospheric pressure.

Write the difference ΔE between the potential at $A1$ and the potential at B.

4 The difference ΔE is the energy that one has to provide to the system to move from liquid water at room temperature to vapor at 100 degree and atmospheric pressure.
This energy involves two parts: heating the water from 20 to 100 degrees and then transforming the water into vapor.
For the first step one needs the specific heat of water, for the second step one needs the heat of vaporization of water. These data are given in the Data section.
Thus one gets: $D_1 = 80 \times 75 + 41000 = 47$ kJ/mol
To what value of K_1 does this lead?

5 Make the same calculation for ethanol.

III. Mixing water and ethanol

Initially, water and ethanol are separate. In this state each liquid has a potential energy of about 46 kJ and there is no interaction between water and ethanol.

When we mix the two liquids three changes occur simultaneously.

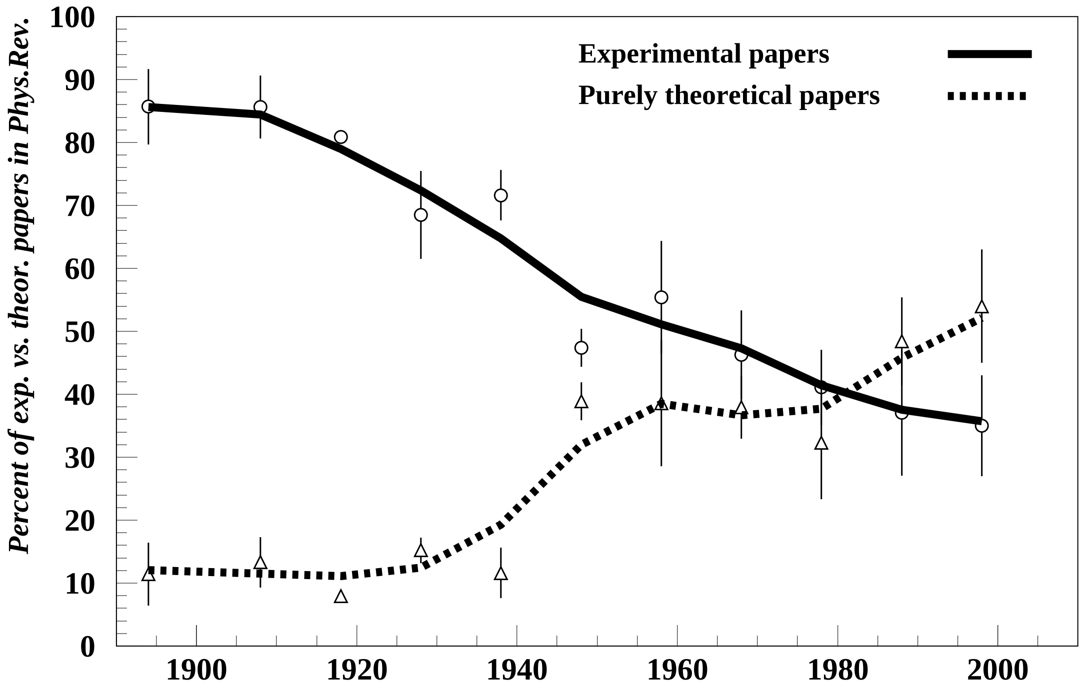
1 The ethanol molecules will come between the water molecules which means that the intermolecular spacing of the water molecules will have to increase. As a consequence, the potential energy of the water molecules will be reduced (in absolute value) by an amount E_1. This energy must be given to the system.

2 Similarly, the water molecules will come between the ethanol molecules which means that the intermolecular spacing of the ethanol molecules will have to increase. As a consequence, the potential energy of the ethanol molecules will be reduced (in absolute value) by an amount E_2. This energy must be given to the system.

3 As the water and ethanol molecules come closer together an interaction between them will appear. This will release an amount of energy E_{12}.

Our observation has shown that there is a temperature increase which means a release of energy by the system. In other words: $E_{12} - E_1 - E_2 > 0$.

Is it possible to estimate $E_1,\ E_2,\ E_{12}$? This will be our nest task.



Percentage of experimental/theoretical papers published in Physical Review. "Physical Review" is probably the most important physical journal. If the current trend continues by 2050 experimental papers will represent only about 20%.