Appendices

Appendix A. An Epistemological Position

Our approach to critical thinking in physics is based on an epistemological position: any group seeking to develop new scientific knowledge aims to produce statements and submit them to critique, either internally or by opening them up for wider discussion. Thus, physics is a field, like others, in which critical analysis is essential. However, some factors seem to us to be particularly favourable for learning critical analysis through physics.

The first is related to the high degree of mathematical formalisation that is the rule in physics. Most statements produced in physics are in the form of mathematical relationships, which is an aid (as long as you have mastered mathematical language) to detecting internal contradictions or becoming more aware of the role of a particular variable in a piece of reasoning. Indeed, as Hulin (1992) argues, “natural language alone (...) is ill-suited to express the relationships between physical quantities, let alone to develop an argument based on these relationships”.

A second favourable factor is the existence of well-defined and measurable quantities in physics. Measurable quantities do of course exist in other fields, but in physics this is the rule and this omnipresence of numerical values makes it possible to test predictions quantitatively. As Ogborn (1999) argues, science is constrained by a continuous effort “to make tight connections between transactional imagination and intransigent reality” which means “taking seriously and systematically developing the simple and obvious thought that although we can think whatever we like, we cannot do whatever we like” (p.17). While it is relatively easy to detect a discrepancy between an expected result and an observed result, it can become more complicated to determine how to explain it. Such a discrepancy may result from the fundamental physical laws at play, from the model of the physical situation, or from the measurements themselves. Fundamental physical laws are rarely challenged directly. In fact, physics is a very structured science aiming at a coherent and

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parsimonious description of the world, a few laws accounting for a large set of phenomena in a specified range of validity: "(…), the value of explanations resides in their enabling us to unify and to organize knowledge. (…). Scientific knowledge is thus unified to the extent that we can derive the largest number of facts from the smallest number of assumptions" (Norris et al. 1989, See also Kitcher 1981; Ogborn 1997; Jenkins 2007; Thagard 2008). This perspective of unification provides essential guidance for deciding what to conclude in the event of confirming evidence or of discrepancy between a prediction and the outcome of an experiment. For instance, Papadouris et al. (2018) have recently taken up Duhem's position (1908): "Not withstanding the critically important role of observational data in scrutinizing explanations, they do not suffice to yield conclusive validity judgments. Appreciating this subtlety is important in that it allows putting empirical evidence in an epistemically informed perspective that avoids overestimating its role" (p. 224). The case of the discovery of Neptune in 1846 is often discussed in this regard (Holton and Brush 2001). A discrepancy between prediction and observation had occurred regarding the trajectory of Uranus. In this case, given the great unifying power of Newton's law of universal gravitation, it was finally decided to seek a new planet rather than reject the theory. In some cases, however, it is the physical law that must be reviewed and not the model (which includes here the number of planets to be taken into account). This then leads to the restructuring of entire parts of physical theory to ensure the coherence of the whole (see the "scientific revolutions" defined by Kuhn 1962). Such restructuring occurred, for example, during the transition from Newtonian theory to general relativity, which now explains the advance of Mercury's perihelion.

In this book, it is this great coherence of physics that we wish to highlight, and the constraints it brings to reasoning, whether in terms of explanations or predictions. In such a framework, requirements are basic: a minimum critical faculty means being able to detect self-contradictory statements or statements that contradict basic laws of physics, and also to identify explanations that are incomplete from a logical standpoint. These contradictions or incompletenesses may be detectable with more or less simple reasoning. In our case, we envisage situations where questionable statements can be identified from a very simple argument, "simple" meaning what is reasonably expectable from novice teachers and even younger students. This emphasis on coherence does not mean that this concern is a sufficient condition for the progress of science. As Ogborn (1999) wrote "Nothing about the process of science guarantees success" (p. 6). But at least can we say that identifying a defect in a particular argument – in terms of coherence or logical incompleteness – is a crucial capacity in the practice of science in general and in physics in particular. This capacity does not cover the whole range of meanings of the expression "critical thinking" (Jiménez-Aleixandre and Puig 2009) but it is an essential asset, a common (minimum) condition for a productive intellectual life whatever the domain.

With regard to physics, one risk deserves to be highlighted. As Ogborn (1999) notes, "There are (…), some areas of knowledge where we may properly speak of practical certainty, that is, of knowledge on which it is appropriate to rely without hesitation until further notice. Doubt vanishes because no serious alternatives remain unexamined and uneliminated. It is probably best to think of these areas of secure knowledge as partial islands in an ocean of unknowing or of partial and insecure knowledge, though the value of their achieved existence is such that we are always liable to overestimate their magnitude" (p. 6). We must bear in mind that whatever explanation we accept as valid must be considered as an intellectual object open to improvement (Ogborn 1997; Papadouris et al. 2018), if not to radical change (Kuhn 1962).

Another risk concerns the idea of simplification. It is clear that explanations in physics are based on models of the material world that leave out some of its complexity. Hence the idea that simplification is both inevitable and fruitful, and that it is therefore legitimate as a first step in the exploration of physical phenomena. But we would stress that certain types of consequences cannot be avoided in a given model, which limits the scope of what can be successfully considered as a preliminary simplification. The emblematic case of the "isobaric hot air balloon" discussed in this book is enlightening in this respect, because the envisaged simplification ruins any hope of a coherent explanation by eliminating a crucial variable: the pressure gradient.

These constraints and risks facing science make critical thinking an essential condition for the development of scientific explanations and the learning of science. As Henderson et al. (2016) pointed out: *(…)* "critique is essential to evaluating which idea is more fruitful, plausible, or simply parsimonious" (p. 1683). We share their view that "Constructing knowledge (…), is not so much a product of one conception being replaced by another (e.g., Posner et al. 1982), but rather a process of weighing alternates and evaluating the balance of probabilities between two competing beliefs – in short – 'a dialectic between construction and critique' (Ford 2008)" (p. 1676). We acknowledge that, with regard to this evaluation process, the considerations we propose here concern only very preliminary steps, i.e. a check on internal consistency, compatibility with widely accepted laws and the logical coherence of explanatory texts.

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Appendix B. A Class Session on Thermal Insulation

This Appendix details a case (previously analysed in Viennot 2013) where a document intended for teachers in lower secondary education shows an internal contradiction in physics. It seems that this has not been detected by the authors of the document, since it is neither recorded nor commented on. This example is provided to support an existence theorem: it is not totally implausible that one encounters, especially during teaching practice, an internal contradiction in physics that is not identified as such.

This class session is proposed in a DVD to promote a type of education that emphasizes inquiry. The presentation is made through a series of episodes, in which various groups are observed, supervised by three teachers (Life and Earth sciences, Physics and Chemistry, and Technology) working in turn. In this composite sequence, each episode illustrates a phase of the process (written in italics on the DVD, as below). After the phase of *Identification of the problem giving rise to the research* (we are on Mars and it is cold), *students suggest strategies to deal with the problem.* On the board, a question is asked*: How to protect buildings and clothing from heat and cold?*

T (teacher) – So, to answer this question we will try to make a list of the materials we could use. So it's up to you to make proposals now.

After this encouragement of the teacher comes a phase called *Collecting ideas and experience protocols.*

S (*a student*) -Survival blankets
T- Survival blankets. So, do you know what the material is? What's on a survival blanket that allows you to survive?
S- Aluminium
T- Yes? For some, yes. So now we're going to list the materials. I'm going to write on the board and then we'll just take some of those materials because we don't have....

The core of the sequence then consists of material proposals by the students, *hypothesis* making, setting up of experiments, all with very active students involved in the discussion. For example, containers the size of a cup are filled with hot water and covered with lids made of various materials. An ice cube is placed on the lid of each container and the time it takes for the ice cubes to melt is compared. In another episode, the experiment is done by placing the sheet of material used for the lids directly on the work table: in both cases, it is with aluminium that the ice cube melts the fastest. This is a crucial step in a teacher-student exchange:

T- So, here it melts faster, it means that aluminium (back to the original hypothesis). Is it a good insulator?
S- No.
T- No. Can it protect us from the cold?
(Chorus students)- No

The analysis presented here focuses on two observations: i) in none of the experiments presented in the DVD there is mention of the geometric dimensions of the material tested as factors to be taken into account; ii) the last episode quoted here presents two conclusions which seem accepted by all and can be formulated as follows: aluminium is not a good insulator, and it cannot protect us against the cold. The first statement is confirmed later, the second is nowhere in the DVD related to the existence of survival blankets containing aluminium.

This conclusion – one cannot protect oneself from the cold with aluminium – is problematic because it is in flagrant contradiction with what was accepted at the beginning of the sequence: the beneficial use of survival blankets. In fact, a physical analysis of the functioning of a survival blanket should consider several energy transfer processes: conductive, convective, radiative. Instead, the conclusion expressed after the experimentation took only conduction into account, whereas the benefits of survival blankets are due to their radiative properties.

Because of the structure of the DVD, it is not known whether the same students confronted these two contradictory ideas – *survival blankets allow you to survive* and *aluminium cannot protect us against the cold*. But the teacher who watches this DVD as part of her/his training, will not know if such a discussion needs to take place or how to conduct it. The DVD implies that there is no problem.

The curious reader will find in Appendix H a physical analysis of the functioning of a survival blanket (see also Viennot and Décamp 2016a). This analysis takes into account several energy transfer processes (conductive, convective, radiative) whereas the conclusion of the discussion reported in this DVD only takes conduction into account.

Reference of Appendix B

Viennot, L. (2013). Les promesses de l'Enseignement Intégré de Science et Technologie (EIST) de la fausse monnaie? *Spirale* n° 52, 51–68. (The Promises of Integrated Science and Technology Education (ISTE): Fake Currency?).

Appendix C. Atmospheric Composition and Radiocarbon Dating

The subject of radiocarbon dating seems to be well known to future physics teachers. It is based on the radioactive decay of atoms of one isotope of carbon ($^{14}C \rightarrow {}^{14}N$ + electron + antineutrino). The law of radioactive decay gives the number N(t) of ^{14}C atoms of an initial population N_0 remaining after a duration t: $N(t) = N_0 \exp(-\lambda t)$. The value of the constant λ is linked to time τ (the "half-life", here 5730 years) at the end of which only half of the initial atoms remain: $\lambda = \ln 2/\tau$. For a given initial population N_0, therefore, there are fewer and fewer radioactive atoms: a measurement of the [$^{14}C/^{12}C$] ratio in a dead organism will make it possible to evaluate the time over which the atoms of the initial population have decayed (^{12}C atoms are stable). In any case, in order to know the value of the exponential and thus the time elapsed since the death of the organism, it is necessary to know the composition [$^{14}C/^{12}C$] of the carbon skeleton at that date. However, it is admitted that as long as it is alive, the [$^{14}C/^{12}C$] proportion of a living organism's skeleton is the same as that of the atmosphere because of the exchanges linked to its metabolism. On the other hand, once death has occurred, these exchanges cease and therefore nothing comes to replenish the ^{14}C population in the skeleton. The question then is how to know the [$^{14}C/^{12}C$] composition of the atmosphere at the time of the organism's death. In response to this question, it is accepted that the composition of the atmosphere is the same as at present. Could it be that in the atmosphere the radiocarbon does not disintegrate? This is absurd! There is only one possibility: a mechanism adds radiocarbon atoms to the atmosphere at the same rate as they disappear through disintegration. This mechanism is linked to the action on nuclei of nitrogen (^{14}N) of neutrons called "cosmic" (actually resulting from the action of cosmic particles on nuclei of atmospheric atoms, e.g. oxygen): this action generates radiocarbon atoms (neutron $+^{14}N \rightarrow {}^{14}C$ + proton). Very well, but how is it that the production thus achieved balances exactly radioactive decay? And how was a given value of the $^{14}C/^{12}C$ composition generated and stabilized?

To facilitate the understanding of these points, we have proposed the analogy below (Décamp and Viennot 2015).

Analogy of Removals

Imagine a country with a stable total population, N_{Tot}. The population is divided into two categories: rural (N_R, e.g. ^{14}C) and urban (N_U, e. g. ^{14}N) populations. Suppose that each year 10% of urban dwellers (from N_U number) move to the countryside and 40% of rural dwellers (from N_R number) move to the city.

Can the population of each category be stable? Yes, if they have values such that the exchanges are balanced, i. e.:

$$0{,}01 N_U = 0{,}04 N_R$$

or

$$N_U = 4/5 \mathrm{N_{Tot}} \text{ and } N_R = 1/5 \mathrm{N_{Tot}}$$

If the urban population is lower than this equilibrium value, there will be more moving from the countryside to the city than in the opposite direction, and therefore the urban population will grow to its equilibrium value. If the urban population is higher than this equilibrium value, there will be more moves from the city to the countryside than the other way around, and therefore the urban population will decrease to its equilibrium value.

Thus, whatever the initial distribution of the population between urban and rural areas, it is the same proportion of inhabitants who will, in the end, settle between urban and rural housing.

This intriguing result is, in fact, due to the multiplicative structure of the temporal rates of change of residence: these are proportional to the existing populations.

This analogy lends itself well to the understanding of radiocarbon dating, as follows:

Table C.1 Elements of questioning and knowledge about carbon-14 dating and the academic level necessary a priori to express them, and possibly answer them

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	(Additional) knowledge element required[a] and accessible at university level before graduation
How is the relative concentration [$^{14}C/^{12}C$] of the studied organism at the time of death found?	Carbon isotopes ^{12}C, ^{14}C	
	Food chains of living organisms, exchanges between plants and the atmosphere.	
What was the composition of the atmosphere [$^{14}C/^{12}C$] at the time of the organism's death?	*At the time of his death, an organism has the same ratio [$^{14}C/^{12}C$] as that found in the atmosphere at that time.*	
	The composition of the atmosphere at the time of the organism's death was the same as it is today.	
If we accept the stability over time of the relative composition [$^{14}C/^{12}C$] in the atmosphere, how can we justify this assertion?	Radioactive decay: The number N(t) of ^{14}C atoms in an initial population N_0 remaining after a time t is $N(t) = N_0 \exp(-\lambda t)$	
	Nitrogen atom, ^{14}N: Composition of the nucleus. The disintegration of a ^{14}C atom produces a ^{14}N atom and the nuclear reaction of a ^{14}N atom with a neutron produces a ^{14}C atom.	
	The time rate of each of these transformations is proportional to the existing population concerned.	Not strictly necessary:
	The total number of ^{14}N + ^{14}C atoms remains constant over time.	neutron +^{14}N ➔ ^{14}C + proton
	See the text for the analogy of removals.	^{14}C ➔ ^{14}N + électron + anti neutrino

[a]Required: at least to ask the question, and possibly answer it

When a radiocarbon atom (^{14}C) disintegrates, it produces (among other things) a nitrogen atom (^{14}N). When a nitrogen atom (^{14}N) reacts with a cosmic neutron, it produces (among other things) a radiocarbon atom (^{14}C). Everything happens as when two populations exchange individuals (who "move"). In addition, the proportionality of exchange rates to existing populations ensures, as in the case of rural and urban populations, the stabilisation of their numbers after a transitional phase, regardless of the initial situation or after accidental situations (for example, for radiocarbon, a volcanic eruption).

Table C.1 summarizes the elements of questioning and knowledge about carbon-14 dating as well as the level necessary a priori to express them, and possibly answer them.

References of Appendix C

Décamp, N., & Viennot, L. (2015). Co-development of conceptual understanding and critical attitude: Analysing texts on radiocarbon dating. *International Journal of Science Education*, *37*, 2038–2063.

Appendix D. Magus Effect for Non-specialists

This example is still a case in which, without necessarily understanding everything about the situation mentioned, we can identify contestable aspects of the proposed reasoning, here a strong incompleteness of the demonstration and an indirect denial of a law. The topic is the non-parabolic trajectory of a ball spinning on itself (Magnus effect, Fig. D1). The author of a popularization document for college teachers explains:

> … we know that pressure and speed are linked. Imagine that there is a pressure difference between two adjacent points in the air. Because of this pressure difference, the air is undergoing a pressure force that tends to accelerate it to the point where the pressure is lower; in a way, the air is pushed by the high pressure. In other words, the speed increases in the lower pressure region. We can therefore sum up by saying that the speed is higher where the pressure is lower and, in an equivalent way, that the speed is lower where the pressure is higher.

This text is supported by Fig. D2. This argument seems to refer implicitly to Bernoulli's theorem, i.e.: When the flow of an inviscid and incompressible fluid (of density ρ) is steady, and g being the gravitational body force per unit mass, the quantity $v^2/2 + p/\rho + g\,z$ (density: ρ ; pressure: p; flow speed v; altitude: z) is constant along a stream line (if $curl\,\vec{v} = \vec{0}$, this quantity is the same throughout the fluid). Note that here no application conditions are mentioned. How do we know now where the speed is *lower*? Lower than what, by the way? The text above suggests a comparison between speeds of the same air mass at different times: "the air is pushed (…) the speed increases". In support of this discussion, a drawing shows two adjacent stream tubes with parallel streamlines as well as two sections with different fluid velocities in one of the tubes. With parallel streamlines, the speeds in question cannot be different for an incompressible fluid. Secondly, the speeds and thus the pressures that we compare are those of two points (above and below the ball) that are not on the trajectory of the same air mass: how could we understand?

Table D.1 summarizes the elements of questioning and knowledge about the text analysed here as well as the academic level which is necessary a priori to express them and possibly answer them.

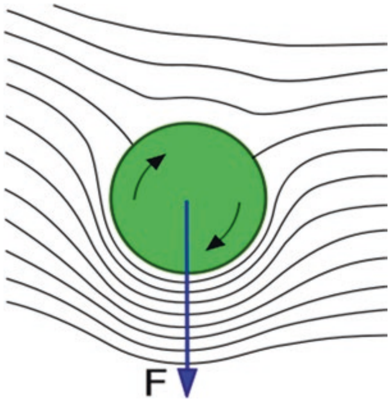

Fig. D1 Magnus effect, for a fluid moving (from right to left) relatively to a rotating ball: the part of the ball in contact with narrower stream tubes is subjected to lower pressure forces

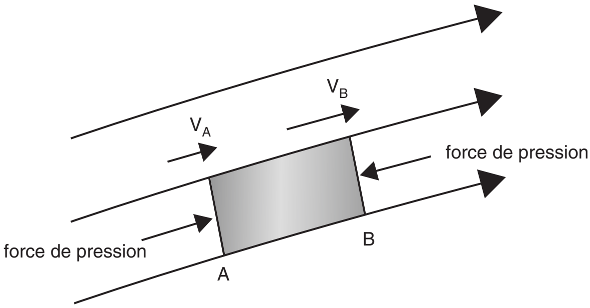

Fig. D2 A figure, in a popularization text, to explain the mutual dependence between fluid speed and pressure

Table D.1 Elements of questioning and knowledge about the text analysed in this Appendix and the level necessary a priori to express them and possibly answer them

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
How can an incompressible fluid move at different speeds (V_A, V_B) across two cross sections (A, B) in a tube of constant cross-section?	Cylindrical stream tube: cross-sections of same area.	Incompressible fluid Flow rate Steady flow *Here, the tube is of constant cross-section:* *If the fluid is incompressible, the velocity of the fluid remains constant along the tube* $\vec{\nabla}\cdot\vec{v} = 0$ *So the explanation proposed here is not valid.*
Which object is concerned by the Newtonian balance implicitly used?	Newton's second law *Here, the object considered is the fluid located in a stream tube between two cross-sections of this tube.*	

(continued)

Table D.1 (continued)

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
Have all the forces involved been taken into account?		Viscosity, Zero viscosity liquid (inviscid fluid) *Here, it is not mentioned that the proposed reasoning is not valid in case of non-zero viscosity.*
How does the comparison of speeds along a given stream tube explain a pressure difference between different points on the ball surface?	*If the explanation is accompanied by a drawing showing the air stream lines around the ball (as in Figure 30), it becomes clear that not all the different points of the ball are affected by the same stream tube. This clarification is not given here.*	As for the relationship between pressure and velocity, Bernoulli's theorem (see text) solves the question for an incompressible and inviscid fluid in a stationary regime. *To achieve a consistent explanation, it must be taken into account that, in all stream tubes, the pressure is assumed to be the same far from the obstacle and that it is more or less decreased in contact with the ball depending on the speed of the air relative to the ball – relative speed which depends on its rotation.*

[a]Required: at least to ask the question, and possibly answer it

Appendix E. The Pierced Bottle and the Range of the Jets

This Appendix draws widely on Viennot 2014, 135–139.

It is common to state that the range of water jets emerging from a pierced bottle and impacting a support at the bottom of the bottle increases with the distance between the hole and the free surface. That suggests (some would say, demonstrates) that at each hole the pressure increases with depth. It is clear that such a conclusion would show a lack of vigilance, coupled with confusion between the accuracy of a conclusion (pressure increases...) and the value of a demonstration. The very principle of this demonstration is contentious (see the calculations below): we want to show the increase in what is often called "hydrostatic" pressure even though we are dealing with a dynamic situation. The standard formal treatment of the situation, detailed below, is to calculate the exit velocity as if the water had fallen from the surface in free fall, at constant pressure – a supreme irony. It is therefore difficult to link the jet range to an outlet pressure, so another variable is chosen: the water exit velocity, which is horizontal. This depends on (the square of) the depth of the hole. Except that, if we actually perform the experiment (it is preferable to use an overflow system to maintain a steady total water height), we observe a maximum range for the mid-height hole (Chap. 2, Fig. 2.8), and equal ranges for holes symmetric about the mid-hole. This is due to the fact that the exit speed of the water is not the only relevant variable. The duration of free fall out of the bottle also contributes to the horizontal distance moved by the water before impact. It is finally the product of these two factors which accounts for the observed impacts. Exit velocity and time of free fall are respectively linked (via their square) to the distance from a hole to free surface and to its distance to the support. The product of these quantities accounts for the position of the impacts.

Standard Calculation

The classic approach is to use Bernoulli's theorem for this situation (Acheson 1990, 10). This presupposes that the flow regime is steady and that the liquid is incompressible and inviscid. The application of this theorem to two points on a streamline (Fig. E.1) located respectively on the free surface (A) and at the water outlet (B, at height h) leads to:

$$v_A^2/2 + p_A/\rho_{water} + g\,z_A = v_h^2/2 + p_B/\rho_{water} + g\,z_B \quad (1)$$

We then assume that the flow speed v_A at the free surface (whose area is much greater than that of the hole) is virtually zero compared with the exit flow speed v_h from the hole being considered. The water pressure is the same at the free surface as at the exit hole, i.e. atmospheric. Eq. (1) is then written.

$$p_{atm}/\rho_{water} + g\,z_A = v_h^2/2 + p_{atm}/\rho_{water} + g\,z_B$$

Therefore, the square of the speed, v_h^2, is proportional to the difference $z_A - z_B$, i.e. the difference between the height of the water surface, H and that of the hole, h:

$$v_h^2 = 2g(H-h) \quad (2)$$

It is interesting to note that this formula is the same as that obtained with the free fall model. The relationship $p_h - p_{atm} = \rho g(H-h)$, where $p_h - p_{atm}$ is the difference in pressure between the altitudes h and H, cannot be used because it assumes

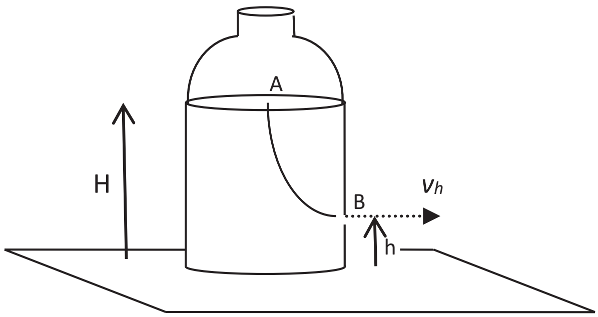

Fig. E.1 Application of Bernoulli's theorem at two points on a streamline for the flow of water within the bottle hydrostatic conditions which clearly do not hold in the case of an accelerating fluid stream.

Another quantity affects the range of the water-jet: the time t_{ff} of the water's free fall outside the bottle, such that $h = (1/2)g\, t_{ff}^2$. The square of this time, t_{ff}^2, is proportional to the altitude h of the hole as measured from the table onto which the jet falls:

$$t_{ff}^{\ 2} = 2h / g \tag{3}$$

Assuming the water jet is horizontal at the exit hole, its range is obtained by multiplying the velocity v_h at the exit hole by the time of free fall, t_{ff} .

$$d = v_h\, t_{ff} = 2\left[h\left(H - h\right)\right]^{1/2} \tag{4}$$

The range of the jet therefore depends on the product of the two distances whose sum is H. With a stable level of water in the bottle, a steady flow regime is observed where the maximum range is obtained for the mid-height hole:

$$\mathrm{h_m} = \mathrm{H}/2.$$

In this model, two holes symmetric about h_m will give rise to jets of the same range.

It should be made clear that practical realisation of this experiment confirms the predicted sequence in the observed water jet ranges, but not their numerical values. Questions remain about the holes as well as about the viscosity of the water. For further details, see (Planinšič et al. 2011).

Table D.2 summarizes useful questions and knowledge about the documents on the pierced bottle discussed in this Appendix, as well as the academic level needed a priori to express them, and possibly answer them.

Table D.2 Elements of questioning and knowledge about common documents on the pierced bottle

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
According to the documents quoted in Fig. 2.8, a hole at the level of the support would result in a greater range, but the water, accelerated by its weight in the vertical direction, would immediately hit the support.	Free fall, time equations in horizontal and vertical directions.	
	It is necessary to take into account the time of free fall outside the bottle, not only the exit speed.	Condition of independence of horizontal and vertical movements: absence of viscosity and friction of water on air

(continued)

Table D.2 (continued)

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
	Energy conservation (no dissipation) for a drop that passes through an incompressible and inviscid fluid *(here under the effect of gravity).*	Viscosity, Inviscid fluid
		The energy balance can be presented as an application of Bernoulli's theorem.
	Extremum of the function $d(h) = 2[h(H-h)]^{1/2}$	
	The derivative of this function is zero for h = H/2	*Here, it is not mentioned that the proposed reasoning is not valid in the case of non-zero viscosity (this is all the more the case when the water is cold), or of appreciable friction on the air (this is all the more the case when the path of water in the air is long).*
What is the relationship between this analysis and the increase in hydrostatic pressure with depth?	Hydrostatic pressure	
	The pressure in the water at equilibrium is not in question here. We are only talking about water in accelerated fall.	
It is useful (and unusual) to point out that the treatment of this problem via Bernoulli's theorem is nothing but the expression of an absence of dissipation in water. Not mentioning the conditions of application of Bernoulli's theorem further blurs this idea. It is common to forget the role of the time of free fall and to consider only the exit speed of the drop.		

[a]Required: at least to ask the question, and possibly answer it

References of Appendix E

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Appendix F. Batteries, Electrolytic Cells and Direction of Current

In the first years at university, electric circuits is a topic sometimes developed after electrostatics and magnetostatics and treated as a special case of electromagnetism. While some presentations of this kind are well conducted and consistent, a "simplified" version of this approach in high school can pose problems of coherence and completeness. Thus, we often find the following explanation, based on electrostatics, to explain the direction of the current (Academy of Bordeaux, n.d.):

> Between the two terminals of a battery there is a permanent difference in the density of the free electrons: the negative terminal has a higher than normal electron concentration while the positive terminal is deficient in electrons. If an electrical circuit is connected to the battery, the free electrons of the circuit are attracted by the positive terminal, repelled by the negative terminal of the battery. They circulate from the negative terminal to the positive terminal outside the generator.

None of the sentences in this text violates the laws of electrostatics, but the last sentence (*outside the generator*) invites us to wonder what is going on inside the battery and to question this simplified explanation. Indeed, if a higher concentration of electrons creates a charge singularity, shouldn't it attract isotropically the positive charges? And if so, should we understand that the direction of current inside the battery is contrary to the direction of current outside the battery? A well-informed physicist knows that this is not the case, but at the same time, they will look with caution at this type of explanation involving only two specific charge singularities.

However, this type of explanation can be found again in the study of electrolytic cells (Academy of Bordeaux, n.d.): "As an ionic solution is liquid, all the particles that make it up move freely (property of the liquid state) and randomly. When this solution completes an electrical circuit, all the particles carrying electric charges (the ions) no longer move freely, but will be attracted by the generator terminals:

> The anions (bearing negative charges like electrons) are attracted by the + terminal of the generator[...].
>
> The cations (bearing positive charges) are attracted by the – terminal of the generator. […].

Criticism is made easier here by the fact that ions are explicitly mentioned, ions which are known to be involved in conduction inside the battery: It is intriguing that they are attracted by a terminal of the generator when they are in the electrolytic cell but repelled by the same terminal when they are in the battery (Fig. F.1).

Other formulations, in terms of surface charge distribution, make it possible to improve these explanations (Fig. F.2). This is the case, for example, of the presentation adopted by Chabay and Sherwood (2006). Here, this distribution explains the field inside a conductor and therefore the direction of the current.

Unfortunately, as the electric field circulation along a closed circuit is zero ($\vec{\nabla} \wedge \vec{E} = \vec{0}$ in direct constant current), the electrical potential along an electric circuit necessarily has a maximum and a minimum (unless it is uniform). Our initial

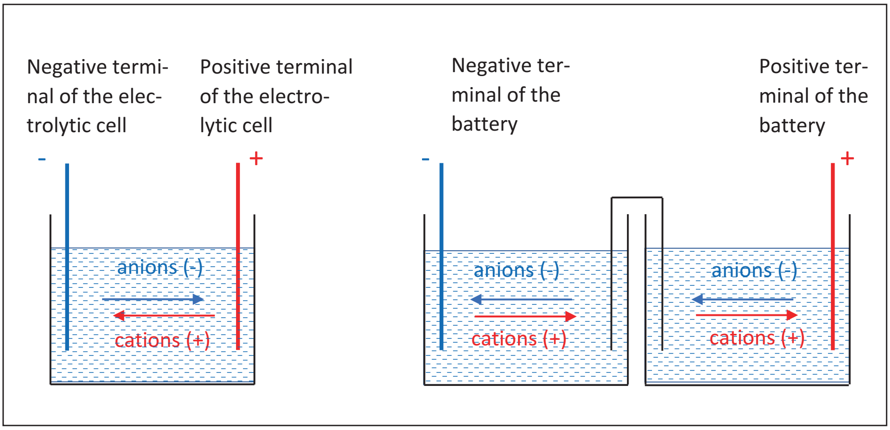


Fig. F.1 The migration of ions in an electrolytic cell is often explained by the fact that the (positively charged) cations are attracted by the negative electrode of the electrolytic cell and that the (negatively charged) anions are attracted by the positive electrode of the electrolytic cell. It is intriguing to see that the migration of ions in a battery is in the opposite direction

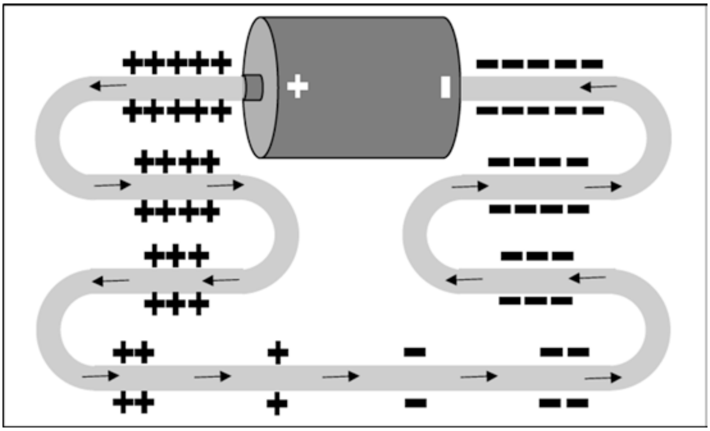
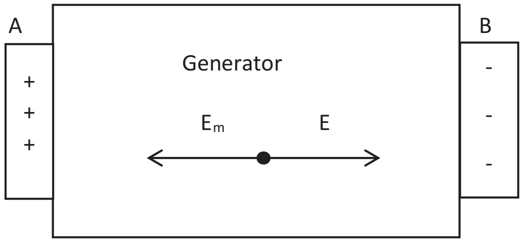


Fig. F.2 (repeat of Fig. 2.10): Charge distribution in a simple electric circuit in a quasi-stationary regime. Surface charges are represented at different points of the circuit so that the charge gradient and the resulting field are explicit. See in particular Chabay and Sherwood (2006). Not shown here, the charges located on the curved parts of the circuit are essential to explain that electrons follow (on average) the wires

question can then be expressed in terms of potentials: if the electrons go in the direction of the potential gradient outside the battery (and possible positive charges go in the opposite direction), can the anions go in the opposite direction to the potential gradient inside the battery (unlike cations) (Fig. F.1)? Overall and seen from the outside, it seems that "in a generator,[...] the current[...] circulates in the direction of increasing potential" (Université de Compiègne n.d.).

Fig. F.3 Figure illustrating the electric field and the electromotive field within a generator (Bruhat 1963)



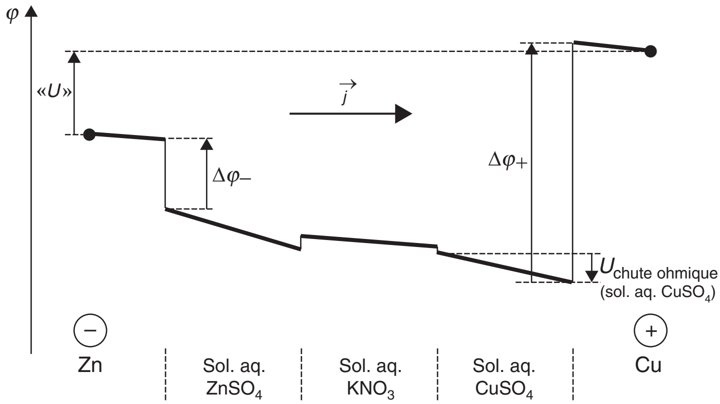


Fig. F.4 Potential profile in a Daniell electrochemical cell (Lefrou et al. 2012, p. 73). U is the potential difference between the terminals of the cell, the terms $\Delta\varphi^-$ and $\Delta\varphi^+$ represent the potential drops between each electrode and the liquid. $\vec{j}$ is the current density

To avoid this paradox, different proposals are available. The most traditional is to postulate the existence of a second field called "electromotive". We find trace of it in this extract from Bruhat (1963): "The essential characteristic of a generator is to create, by various mechanisms, an electromotive field" (p. 251). The figure accompanying this excerpt is explicit (Fig. F.3).

The raison d'être and the interaction associated with this electromotive field are not mentioned.

Other authors, cautiously, move the problem away from the domain of dynamics (or even physics) and simply talk in terms of energy: on this occasion, it is often mentioned that chemical energy is converted into electrical energy without any clear definition of what these terms refer to. Another approach is to use a hydraulic analogy. Its proponents, as well as being well aware of the problem, allude to a "pump" which allows the water in the circuit to "rise" without, again, the physical mechanism of this "pump" being precisely identified. However, a more detailed examination of the situation makes it possible to remove ambiguities and convince oneself that the ions circulating inside the generator are moving in accordance with the laws of electrostatics, as illustrated in Fig. F.4.

Table F.1 Elements of questioning and knowledge useful to discuss common documents on the circulation of charges within a battery

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
In which direction and why do charges circulate inside a battery?	*Positive charges are attracted by negative charges and reciprocally.*	$\vec{E}$ electric field
		V electric potential
		At a point where there is an electric field $\vec{E}$, the positive (or negative) electric charges are subjected (among other things) to a force which is of same direction as (or opposite to) this field. In a medium of conductivity the density of current at this point is: $\vec{j} = \sigma \vec{E}$
		Along a field line, the electric field is directed towards the decreasing potentials.
		Oxidation potential
		$\vec{E} = -\overrightarrow{grad}\,V$
Teaching rituals: In a closed circuit, a reasoning based on the attraction/repulsion by the charges on the ends is used to account for what happens outside the battery, a reasoning that is abandoned inside the battery: In this case, the notions that dominate or have dominated the explanation of what happens inside the battery are: - an *electromotive* field - the values of the oxido-reduction couples in play.		

[a]Required: at least to ask the question, and possibly answer it

Figure F.4 shows that there are two important potential jumps. The fact that these two jumps are not of the same size explains the potential difference between the terminals of the cell on open circuit ($E = \Delta\varphi^+ - \Delta\varphi^-$). In closed circuit, the potential difference U between the terminals is slightly smaller, given the potential drop inside the cell due to the current I (which is the same as outside the cell) through the internal resistance r: $U = E\text{-}rI$ (where $E = \Delta\varphi^+ - \Delta\varphi^-$).

Table F.1 summarizes elements of questioning and knowledge useful to discuss common documents on the circulation of charges within a battery, as well as the level needed a priori to express them, and possibly answer them.

References of Appendix F

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Appendix G. Capillary Rise and the Force That 'Lifts' the Liquid

This appendix details the problems posed by a typical analysis of the equilibrium involved in capillary phenomena and provides a more satisfactory explanation.

Figure G.1 shows a common pattern for the analysis of capillary rise (often water in a glass tube) and for the calculation of the contact angle θ between liquid (L) and solid (S) in the presence of gas (G).

The coefficients (γ_{LG}, γ_{SL} and γ_{SG}) refer to the forces per unit length drawn at the interfaces concerned, respectively. Thomas Young establishes in 1805 the formula linking these coefficients and the angle of contact θ:

$$\gamma_{LG}\cos\theta + \gamma_{SL} - \gamma_{SG} = 0 \qquad (1)$$

A thermodynamic approach of this situation was proposed in 1878 by Gibbs. In this approach, the coefficients take on the meaning of free energy per unit of interface surface area at constant temperature. The equilibrium state corresponds to a minimum of this energy and therefore to a zero value of its variation with an infinitesimal displacement of the contact line. We can now interpret, for each interface, a term of the γ *dS* type as the work done by a force $\gamma\overrightarrow{dl_1}$ moving through a displacement $\overrightarrow{dl_2}$ in its plane ($\overrightarrow{dS} = \overrightarrow{dl_1} \times \overrightarrow{dl_2}$). Then, to cancel the variation of free energy per unit surface area for a vertical displacement of an element of the contact line comes down to writing that the sum of the terms $-\gamma_{LG}\cos\theta\, dl_1$, $-\gamma_{SL}\, dl_1$, *and* $\gamma_{SG}\, dl_1$, is zero, as with relationship (1).

The resulting relationship resembles a force balance that would be zero in a vertical direction, as suggested by Fig. G.1, but the horizontal direction poses a problem from this point of view.

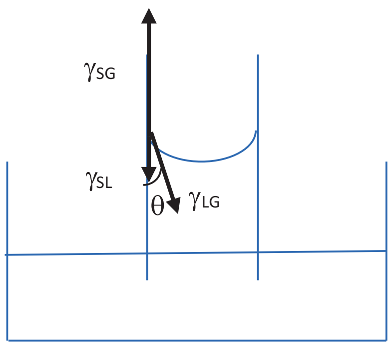

Fig. G.1 Capillary rise and contact angle between liquid (L) and solid (S) in the presence of gas (G); γ_{LG}, γ_{SG} are γ_{SL} are interfacial tensions (forces per unit length) for the liquid/gas, solid/gas and solid/liquid interfaces respectively, and θ is the contact angle

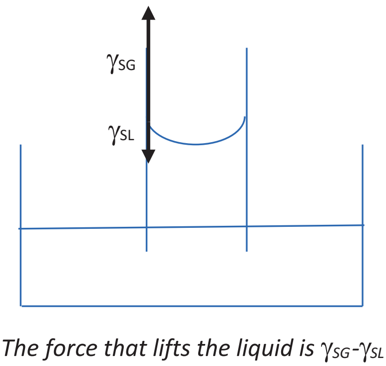

Fig. G.2 A common explanation of the capillary rise (notations as in the previous figure)

In addition, there is no way to connect these "forces" to the column height above the surface level in the tank. In fact, considering only two forces (Fig. G.2, see Viennot 2015) allows a calculation of the height of the liquid column, in line with this comment found in a popular book for physics teachers in lower secondary education: "The force that lifts the liquid is $\gamma_{SG} - \gamma_{SL}$ "(Quéré 2001, p. 158).

Finally, some authors (Berry 1971; Brown 1974; Das et al. 2011; Marchand et al. 2011) question the status of the forces – often qualified as "fictitious" – involved in these explanations, including the fact that they often seem to "pull" on an immaterial line. They analyse molecular interactions and their consequences in terms of localized forces around the interfaces, involving molecules on a typical thickness of two or three molecules. The domed shape of a water or mercury drop deposited on a horizontal support visually attests to the reality of these interactions and the associated surface tension. But from there to understanding the effects of these interactions tangentially on the surface, there is an important step forward.

To summarize the reasons for frustration with the documents described above (Figs. G.1 and G.2), there are at least four.

1. What looks like a balance of forces is not balanced in a horizontal direction.
2. These "*forces*" seem to act on lines (dimension: 1) and not on specified objects with a non-zero mass.
3. The text does not provide a means to account for the height of the water column above the surface in the container at equilibrium.
4. A smooth, vertical glass wall can only attract a molecule of water horizontally, for symmetry reasons (Das et al. 2011; Marchand et al. 2011). It is therefore impossible for a force involving such a glass wall to *lift* the liquid vertically.

One way to solve all these difficulties is to construct a dislocated diagram for the liquid corner that borders the free surface of the upper meniscus, the rest of the water in the column, the rest of the water in the container and the vertical glass wall (Fig. G.3). Taking into account the equilibrium of the liquid corner, the force modules per unit length of the air/water/glass contact line are respectively:

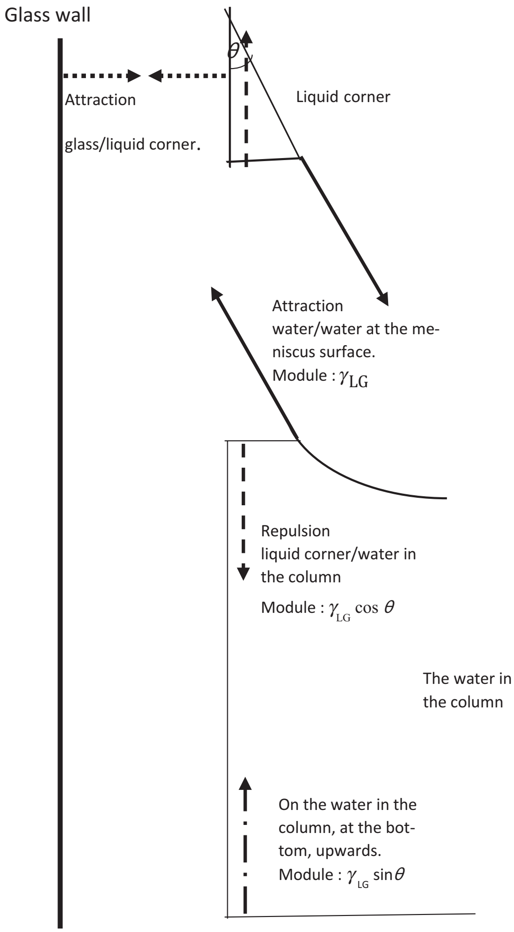

Fig. G.3 Capillary rise: 'dislocated' diagram concerning objects (liquid corner, glass and water in the column) defined by an element of the contact line between water, glass and air (perpendicular to the figure). The only complete free-body diagram (by unit length of the line of contact) is on the liquid corner. The weight of the liquid corner is neglected with respect to the other forces, the weight of the liquid column, P, is not represented (for a column of height h, $\boldsymbol{P} = \rho_{wat}\, \pi r^2_{tube} h\, g = \gamma_{LG} \cos\theta\, 2\pi r_{\mathrm{tube}}$) and the horizontal and repulsive interaction between the water in the column and the glass wall is not shown. This diagram shows the zero force balance on the liquid corner and the overpressure in the water near the vertical wall. The role of atmospheric pressure is not represented: it exerts a normal force on each external surface (even immersed) of the various objects in play (liquid corner, liquid column, glass wall, …) whose total contribution to the Newtonian balances is zero. The only complete free-body diagram (by unit length of the line of contact) is on the liquid corner. Figure partly based on Das et al. 2011 and Marchand et al. 2011

Attractive interaction between glass and liquid corner, horizontal: γ_{LG} sinθ

Repulsive interaction liquid corner/the rest of the water in the column, vertical: γ_{SG},- $\gamma_{SL} = \gamma_{LG} \cos \theta$

Attractive interaction water/water, tangential to the free surface of water: γ_{LG} (vertical component: γ_{LG} cosθ, horizontal component: γ_{LG} sinθ).

The apparent contradictions pointed above disappear. The equilibrium of the water in a cylindrical column implies that the vertical force component $\gamma_{LG} \cos \theta$. $2\pi r$ is opposed to the weight of the water, $\rho_{wat}\ \pi r^2 h\ g$ (liquid cylinder radius: r, height: h, density: ρ_{wat}).

It follows that

$$h = 2\gamma_{LG} \cos\theta / \rho_{wat}\, g\, r$$

It can be observed that the height in question is inversely proportional to the radius of the tube, at given surface tension (Jurin's law).

It is particularly interesting to examine the paradox pointed out in Chap. 4. A smooth and vertical glass wall can only attract water molecules in a normal direction to the wall – here horizontal. How, then, can we speak of a "force that lifts the liquid"?

In fact, the difficulty stems from an overly local analysis of what causes capillary rise. In line with the habits of common reasoning (Chap. 3), attention is focused on what is visibly moving, i. e. the top of the column, and seeks a cause located in the same place. Hence this location at the very top of the liquid corner is commonly chosen for the forces that are supposed to explain the energy changes affecting the whole system. But nothing pulls the liquid up at this point. On the liquid corner itself, there is actually a thrust, which is provided by the liquid molecules compacted all along the wall due to the horizontal attraction they undergo. This analysis makes it possible to understand that at the other end of this compressed zone (here: below) a force is necessarily exerted (here: upward), which blocks the line of compressed molecules in one way or another. We can imagine a tube going down to the bottom of the vessel, which provides this blocking force. The discontinuity due to the lower orifice of the tube may also be responsible for an upward force, since the symmetry invoked above ceases to exist. From then on, the vertical equilibrium of the water column is conceived without particular difficulty, when all the vertical forces acting on it are taken into account, both at the bottom and at the top, including its weight.

The Centrifuge Analogy

An analogy can help us to understand these elements of analysis (Viennot 2015). It is a centrifuge (cylinder radius R) without a cover, partially filled with water and rotating (angular velocity ω). In the rotating frame of reference, a dynamic equilibrium implies a horizontal centrifugal force. This (inertial) force plays a role partially similar to that of the attraction of water molecules by glass, in that it *pushes* these

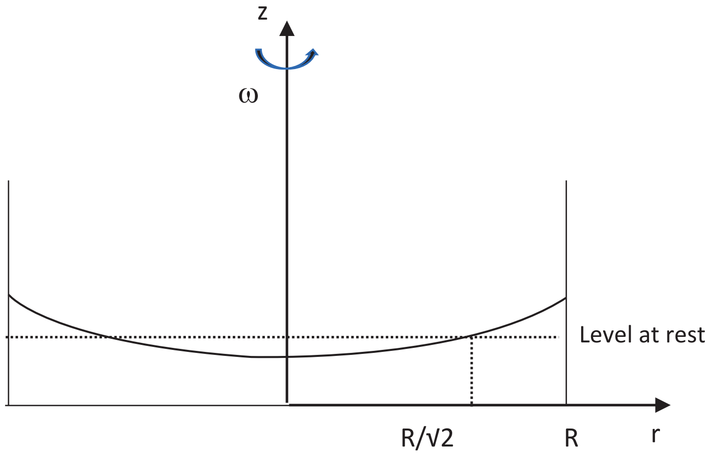

Fig. G.4 Dynamic equilibrium for a rotating fluid in a cylindrical centrifuge of radius R at constant rotation velocity ω

molecules horizontally towards the vertical wall against which they pile up. The free surface takes a paraboloid shape (Fig. G.4). Given the conservation of water volume, the centre of mass of the water is higher than at rest. A greater vertical force than the weight therefore acted on the water during the acceleration phase. Nothing drew the water from above, therefore it was pushed upward from below. It was the bottom of the vessel that exerted this additional repulsive force. Of course, the scale of the phenomenon is quite different from the case of a capillary rise: the compression of the rotating water concerns a large part of the vessel and not a zone with a few molecular diameters of thickness. But the main ingredients of the explanation are there: stacking of molecules piled up close to the wall because of a horizontal interaction with the glass and greater action of the support of the water on it, in a vertical direction, than at rest. In any case, we can clearly see from this analogy that it would be incongruous to analyze the situation of the centrifuge with a force that would lift the liquid by pulling it upwards.

With or without analogy, the analysis summarized in Fig. G.3 solves the problems raised in the four main critical arguments listed above. One might wish that these criticisms could be expressed by people who have not yet reached this clarification, but this is not the case in general, far from it (Viennot and Décamp 2018). Even after understanding the phenomenon and the explanatory value of the dislocated diagram, there is still, sometimes, a great resistance to questioning the diagram in Fig. G.1, as in this interview with a future teacher at the very end of her education:

> Participant –[…] There (on the diagram in Fig. G.1), there are the three forces that start from the point of contact between the three, uh, so, uh, that's what's different, uh, from mechanics.
> Interviewer – Do you mind if it's different?
> - No, I'm not particularly shocked.
> - You're not shocked, all right. It's not like mechanics, you tell me, but it doesn't matter?

- No, I don't mind.
- You would accept that there is a particular logic for capillarity which is not the logic of mechanics?
- Yeah, I wouldn't mind.
- Yeah, so there might be a type of balance just for capillarity?
- Maybe, maybe.

When the imperative of consistency is not perceived, the educator may find it difficult to encourage criticism. On the contrary, when this imperative is perceived and reasonably achieved, there are eloquent comments of satisfaction:

Interviewer – It is more complicated, you will confess (the diagram in Figure G.1 than the one in Fig. G.1)

Participant – Ah no!

- Ah no?

- Just because, there are more things doesn't mean that it's more complicated (...) No, no, it's not more complicated in the sense that we understand better.

Table G.1 summarizes elements of questioning and knowledge useful to discuss common documents on capillary rise, as well as the level needed a priori to express them, and possibly answer them.

Table G.1 Elements of questioning and knowledge useful to discuss common documents on capillary rise

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
If the diagram in Figure 37 were to be interpreted as a free body diagram, why is this diagram not balanced in a horizontal direction?	Free body diagram	
	Second Newton's law	
	Here, it is not possible to interpret this diagram as a balanced free body diagram.	
If the diagrams in Figure 37 and Figure 38 were to be interpreted as a free body diagrams, on which system are the forces in question supposed to be exerted?	Free body diagram	
	Second Newton's law	
	Here, it is problematic to interpret these diagrams as concerning forces acting on a (mass) system. The term "interface", often used, suggests an immaterial line. It should be specified which molecules are concerned by these diagrams.	

(continued)

Table G.1 (continued)

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
If the diagrams in Figure 37 and Figure 38 were to be interpreted as free body diagrams, how would they account for the existence of a water column in the tube?	Free body diagram	
	Second Newton’s law	
	Here, it is problematic to interpret either scheme to justify the presence of the water column, since it is not specified on which system these forces are exerted.	A way to answer the questions asked is proposed in Figure 39. The forces per unit length of the contact line called *interfacial tensions* concern the molecules of each interacting body located near the separation surface, over a thickness of a few molecules.
	If these forces (by unit length of contact line) were supposed to be exerted on the water at its free surface, we observe that:	
How could the glass wall (homogeneous, smooth and vertical cylinder) exert a force other than horizontal on a water molecule?	*- the diagram in Figure 38 appears to be balanced in a vertical direction but does not mention the weight of the water concerned;* *- the diagram in Figure 38 has only two forces left (why?) and could be understood if something pulled the water upwards: it would be enough to add the weight of the column.* *However, a* glass wall (homogeneous, smooth and vertical cylinder) *can only exert a horizontal force on a water molecule.*	
How can the analogy of the open centrifuge (Figure 40) shed light on capillary ascension?	Free body diagram	
	Second Newton’s law	
	The intuition of what happens in a centrifuge makes it possible to access the fact that the water rises on the edges without being drawn upwards at the level of its surface. So it is pushed from below.	
	Acceleration in a planar, horizontal, circular movement	
	The expression of the force exerted by the wall on a fluid element of mass dm ($d\vec{f} = - dm\,\omega^2\,\vec{r}$) *and therefore of its reciprocal, is not even necessary. It is sufficient to understand that the acceleration of the fluid element is horizontal, and therefore also the wall-fluid interaction.*	

[a]Required: at least to ask the question, and possibly answer it

References of Appendix G

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Appendix H. Which Side to Put the Survival Blanket on?

Everyone knows that a survival blanket can help protect against the cold. Typically, it is an ultra-thin film (13 μm) of Mylar with one silver and the other gold. The common and recommended use of these products is to place the silver side towards you to protect yourself from the cold (towards the outside if it is necessary to protect yourself from heat). The reason given is that the silver side is more reflective and will therefore more effectively return the "heat" (as is often said) to the person at risk of hypothermia. In fact, a physical analysis of the situation in question (Viennot and Décamp 2016) does not make this choice obvious. For an opaque body, more reflectance means less absorbance and therefore less emissivity (see Table H.1). As can easily be seen from the experience shown in Fig. H.1, the emissivity of the silver side is lower than that of the gold side, which means that the reflectance of the silver face is higher than that of the gold face. One might wonder: for a blanket with only one silver side, wouldn't turning it inward lead to losing more energy by radiation towards the outside, because of the golden side? There is a dilemma.

A first step in understanding this physical situation is therefore to recognize that it escapes the obvious. Experimentation with teachers at the end of their studies (master's degree MEEF 2, Viennot and Décamp ibid.) shows how difficult it is for them to distance themselves from a common idea, reinforced by the "Red Cross" stamped instructions for use. As noted above, one in seven participants was able to

Table H.1 Relationships that model energy transfer by radiation (Griffiths 1999, see also Besson 2009)

For incoming radiation R, with a « spectral irradiance » $E_e(\nu)$ and « irradiance » (power per unit of area perpendicular to R) $E_e = \int_0^\infty E_e(\nu)\, d\nu$, the power *absorbed* per unit of area perpendicular to R is $\int_0^\infty a(\nu)\, E_e(\nu)\, d\nu = a_r E_e$
where a_r is the overall absortivity for all radiation R and is equal to the mean value, weighted by $E_e(\nu)$, of the absortivities $a(\nu)$ of all frequencies.
The total power *emitted* by a body at absolute temperature T per unit of area, or « radiant exitance», $M_e(T)$, is related to the radiant exitance of a black body at the same absolute temperature by the formula: $$M_e(T) = \int_0^\infty e(\nu)\, M_e°(T, \nu)\, d\nu = e_t\, M_e°(T) = e_t\, \sigma T^4$$
σ is the Stefan constant. $M_e°(T, \nu)$ is the « spectral radiant exitance » of a black body at absolute temperature T. The overall emissivity, e_t, is defined as the ratio between the total power emitted per unit of area by a body at absolute temperature T and that of a black body at the same temperature. e_t is equal to the average value, weighted by $M_e°(T, \nu)$, of the emissivities of all frequencies.
$a(\nu) = e(\nu)$ for every ν; these coefficients can strongly vary with frequency.
Black body: $a(\nu) = e(\nu) = 1$ for every ν and $M_e°(T) = \sigma T^4$.

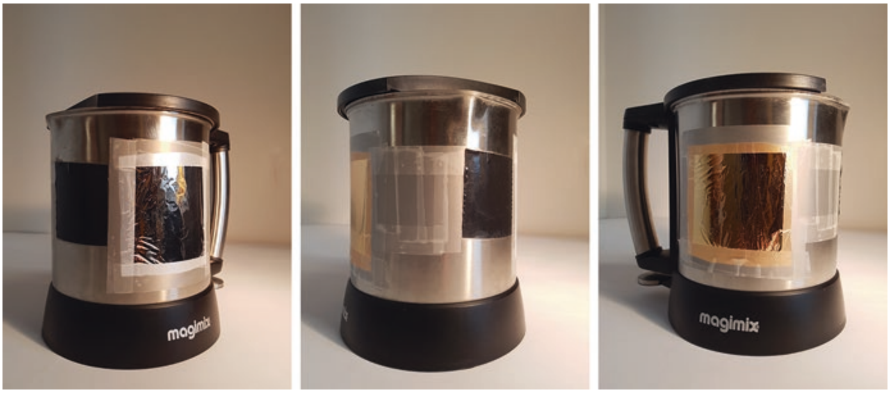

Fig. H.1 Samples of different materials glued to a metal kettle filled with boiling water: the temperatures displayed by a commercially available infrared radiometer are very different (survival blanket, silver side: 27 °C; semi-transparent adhesive tape: 95 °C; black adhesive tape: 96 °C; survival blanket, gold side: 38 °C). The radiometer displays the temperature that a black body emitting as much power as the target object per unit area would have. In practice, for an object of a given temperature, the temperature displayed by the radiometer is always lower than the temperature of the object, and this displayed temperature is all the greater as the emissivity of the object is higher"

use the experience in Fig. H.1 to challenge their initial idea without delay, even though they knew very little about the energy transfers involved (an "early critique" as defined in Chap. 5).

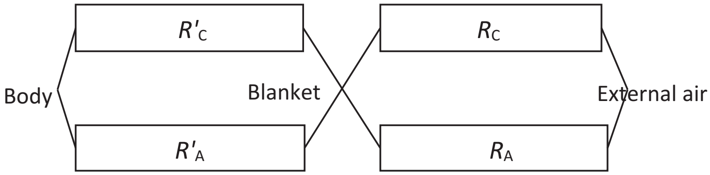

Fig. H.2 Electrical analogy for the transfer of energy between a person to be protected and the external environment

To go further, we can propose a simple model that distinguishes three objects – the person to be protected, the survival blanket and the outside air – each considered as having a single temperature (*Tp, Ts* and *Te* respectively). Between these objects, the net transfers envisaged are of two types: conductive-convective (coefficient C) and radiative (coefficient A); these occur in parallel. We consider the case where there is no direct solar flux on to the person to be protected. In linear approximation, the energy flow to the outside is then written

$$\Phi = \left(C' + A'\right)\left(Tp - Ts\right) = \left(C + A\right)\left(Ts - Te\right)$$

where the coefficients C' and A' are relative to the zone between the person and the cover, while the coefficients C and A are relative to the zone (*boundary layer*) between the cover and the outside air. The radiative coefficients denoted A_a, A_o respectively concern the case where the silver or gold side is facing outwards.

All the transfer relationships (in this case energy) are then analogous to those that describe the electric charge flows (the currents) in a circuit schematized in Fig. H.2 according to potential differences (of which the equivalents here are temperature differences). It is then a question of comparing the equivalent coefficients of conduction (G: inverses of equivalent resistances) in the configuration "silver outside" and "gold outside".

One way to do this is to examine their difference:

$$G_a - G_o = \frac{\left(C' + A_o\right)\left(C + A_a\right)}{C' + A_o + C + A_a} - \frac{\left(C' + A_a\right)\left(C + A_o\right)}{C' + A_a + C + A_{o.}}$$

$$G_a - G_o = \frac{\left(C - C'\right)\left(A_o - A_a\right)}{C' + A_o + C + A_a}$$

This is zero if $C = C'$, i. e. if the conduction coefficients for conductive-convective transfer are identical on each side of the blanket. Then the orientation of the blanket has no impact on the transfer. If $C \neq C'$, since $Ao > Aa$, the sign of *Ga-Go* is the same as the sign of $C - C'$. In practice, in conditions favouring a high energy transfer towards the outside by conduction-convection ($C' < C$, wind and rain, $Go < Ga$), it is necessary to put the golden side outside. In other conditions ($C' > C$, dry and calm weather), the silver side must be outside (Fig. H.3).

Table H.2 summarizes elements of questioning and knowledge useful to discuss common documents on the survival blanket, as well as the level needed a priori to express them, and possibly answer them.

Fig. H.3 The best decision to protect ourselves against cold depends on the weather

Table H.2 Elements of questioning and knowledge useful to discuss common documents on the survival blanket

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
Is it obvious that you have to turn the silver side of the blanket towards you to protect yourself from the cold?	For a first approach:	
	The silver side reflects more radiation (the 'heat') to the body (and emits less), but the gold side radiates more outwardly (reflects less).	
	Here, with only one silver side, it is necessary to find the best compromise between better reflecting thermal radiation towards oneself while wasting power towards the outside, or less reflecting thermal radiation towards oneself while reducing power dissipation towards the outside.	

(continued)

Table H.2 (continued)

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
How to find the best compromise, when there is only one silver side?	Relationship between electrical potential (or here: The temperature difference), electrical (or here: Thermal) resistance and intensity (or here: Energy flow)	Action of a body on radiation. Reflection coefficient, *r*; transmission coefficient (zero for an opaque body), *t*; absorption coefficient, *a*.
	Equivalent resistance for dipoles in series or in parallel	
		Emissivity of a body.
		Box 9
		The model presented in the text and its electrical analogy solve the dilemma:
Common idea: To protect yourself from the cold, you have to turn the silver side of the blanket towards you, because that is how the "heat" is best reflected back to the body to be protected. This reasoning ignores the energy emitted to the outside by the golden side.		

[a]Required: to at least ask the question, and possibly answer it

References of Appendix H

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Appendix I. Water Pressure and Osmosis

The Basics About Osmosis

A prototypic situation for the osmosis phenomenon consists of two vessels separated by a semi-permeable membrane, i. e. one that can pass (in both directions) a solvent but not a solute dissolved in this solvent. Typically, osmosis occurs when solutions of different concentration are in contact with each side of a semi-permeable membrane as shown in Fig. I.1 (the membrane is located at the bottom of the U-tube).

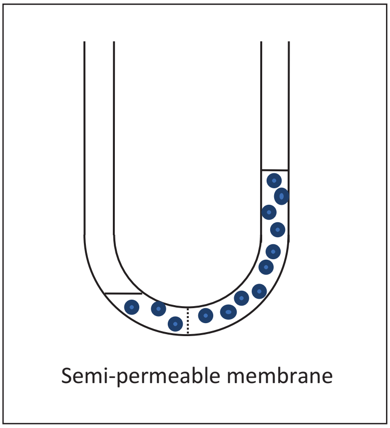

Fig. I.1 An evocative representation of a situation of osmotic equilibrium: the small circles suggest the presence, in different concentrations on either side of the membrane, of solute in the solvent (which is shown only by its level in each branch)

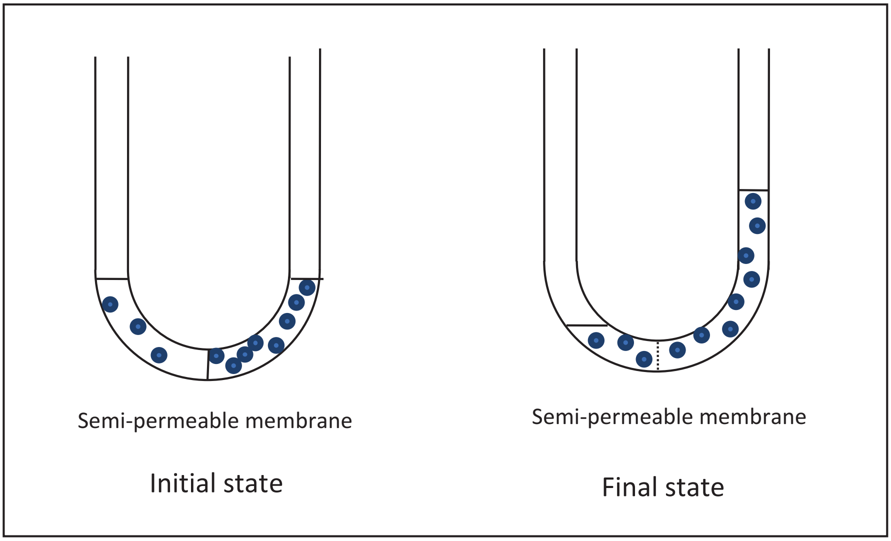

Fig. I.2 Repeat of Fig. 4.1, a type of drawing frequently observed (especially on Wikipedia) to introduce the phenomenon of osmosis, and which suggests that at equilibrium the concentration of solute is the same on both sides of the membrane

The equilibrium is achieved when a quantity relating to the solvent, in this case the "chemical potential of the solvent in the presence of solute", has the same value on both sides of the membrane. The chemical potential in question depends on the temperature, pressure and concentration (see Table 16 and Diu et al. 1989, 408–410). In the case of an (isothermal) equilibrium in the U-tube in Fig. I.2, there are therefore two possible cases: either the concentration of the solute and the liquid height in the branch are both identical on each side, or the concentrations of the solute and the liquid heights in the branches are both different on each side. This would be a formal argument in addition to the reasons already mentioned for contesting the diagram in

Fig. I.2, which suggests a balance with identical solutions on both sides and different levels in the branches.

It might be thought that once the content of the preceding paragraph has been accepted, the matter is settled. Then common misconceptions on the subject should no longer apply. These include the one already discussed in Chap. 4 – the concentration of solute would be the same on both sides at equilibrium – but this is not the only one (Viennot and Décamp 2016).

Their long-lasting survival among students who have received courses on osmosis prompted us to explore the understanding of the very idea of fluid pressure in populations likely to have difficulty with osmosis.

Water Pressure

It is very likely that common errors on the subject of osmosis are encouraged by a totally inappropriate view of what happens in a liquid when it undergoes a change while remaining liquid. To simplify, we are now talking about water as a prototype solvent.

Some readers may already be wondering what can change in the water if it doesn't change state, in the sense of a phase change (solid, liquid, gas). However, this is what osmosis is all about: the chemical potentials of water in the presence of solute change until they are equal on both sides of the membrane. Osmosis involves physical movements of the water and there are potentially very large differences in pressure.

It may therefore be useful to reconsider the question of what pressure in a liquid is. Let's start with pure water.

Simply put, we know that the temperature and pressure of pure water can change too. But what happens then *in* the water? The point of this question is that it leads us to consider molecular interactions differently than in an academic way, namely as what should be absent in an ideal gas. In fact, these interactions play a decisive role in the pressure within the liquid itself. Let us imagine that we evaluate the pressure of water just below the free surface as for an ideal gas, that is to say, considering that the force necessary to make the molecules that collide with a wall restart in the opposite direction is due exclusively to this wall. Then we would find that this pressure, called "kinetic", is $p_{kin} = NkT/V$ (with p: pressure, V: volume, N number of molecules, k: Boltzmann constant, T: absolute temperature).

But that value would be far too high, since the volume concentration of water, N/V, is about a thousand times higher than that of the gas that is just above the free surface, a gas whose pressure is evaluated by the same formula.

In fact, the predominantly attractive interactions between the molecules of the liquid contribute to "reverse" the movement of the molecules involved in the collisions with the wall, in other words the molecules within the liquid "pull" on those that hit this wall. This is equivalent to negative interaction pressure p_{int}.

This is why the pressure within the liquid is written: $p = p_{kin} - |p_{int}|$.

If the pressure just above the water is the atmospheric pressure, in the water each of the terms of this difference ($p_{kin} - |p_{int}|$) is an order of magnitude a thousand times greater, and it is this difference that is equal to the (atmospheric) pressure of the gas. This shows the considerable importance of molecular interactions in water.

A question asked in interviews of future teachers at the end of their teacher education programmes reveals how new these ideas are to them (Viennot and Décamp *ibid.*). Although they are aware of the existence of these interactions, they do not easily imagine that it is the change in these interactions that is decisive when a glass of water is moved isothermally from sea level to the top of Mont Blanc, where the pressure is half as high. In any case, we must think twice before adopting the commentary by Valentin (1983) on what constitutes a change in the gas-liquid phase.: "(…) molecules have such a low average kinetic energy that they can no longer withstand the electromagnetic attraction they exert on each other" (p. 13). Because, except in the zone where the surface tension occurs (a few molecular diameters below the surface: see Berry 1971; Brown 1974), the pressure in the water remains positive and therefore the kinetic term is higher than that resulting from the attractive interactions.

Table I.1 summarizes elements of questioning and knowledge useful to discuss common documents on osmosis, as well as the level needed a priori to express them, and possibly answer them.

Table I.1 Elements of questioning and knowledge useful to discuss common documents on osmosis

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
How can a solution be in equilibrium in a U-tube, with, in the other branch, the same solution reaching the same level, but also the same solution reaching a higher level?	Notion of solution	Variation of hydrostatic pressure with altitude. Newtonian equilibrium (second law) in a U-tube.
	Concept of concentration	
	Concept of semi-permeable membrane, symmetry of its properties with respect to both sides.	
	Symmetry with respect to a plane	*Here, the second case (the same solution reaching a higher level) is declared possible, which is contrary to Newton's second law.*
	Here, the second case (the same solution reaching a higher level) is declared possible, which is surprising from the point of view of symmetry.	

(continued)

Table I.1 (continued)

Question to ask ourselves	Knowledge element required[a] and accessible at the end of secondary school	Additional knowledge element required[a] and accessible at university level before graduation
According to the rule stated, what would happen if one branch of the U-tube contained pure solvent and the other a solution?	Notion of solution	
	Concept of concentration	
	Concept of semi-permeable membrane	
	Here, according to the rule stated, the pure solvent would pass indefinitely to the side of the solution, which is questionable from an energy point of view.	
What are the variables on which the chemical potential of the solvent in the presence of solute depends?		It is the chemical potential μ of the solvent in the presence of solute that determines the osmotic equilibrium. This quantity must be the same on both sides of the membrane. This quantity, for a given solvent, depends on the absolute temperature T, the pressure p and the molar concentration C. it is not necessary to know the formula holding for dilute solutions of small molecules: $\mu(T,p,c) = \mu_0(T,p) - CkT$ ($\mu_0(T,p)$: *chemical potential of the pure solvent, k Boltzmann constant*). *So at equilibrium at given T, either pressure and concentration are identical on both sides of the membrane or they are both different.*
What is pressure in a fluid? Why is it the same in the liquid and its vapor at the thermodynamic equilibrium at the interface, although the liquid phase is about a thousand times denser than the vapor phase?	Pressure in a fluid, related to a normal force exerted on the walls and on a pressure gauge.	Intermolecular attractions reduce the effect of wall impacts and introduce a new term - $\lvert p_{int} \rvert$ in the calculation of the equilibrium pressure in the fluid:
	Pressure due to the impact of molecules on a wall.	
	The effect of these collisions depend on temperature and density. If only the wall acts on the reversal of molecules, then pressure at equilibrium is $P_{kin} = NkT/V$	$p = NkT/V - \lvert p_{int} \rvert$ It is not easy to calculate this term. To give an analytical account of osmosis, it is essential to use the chemical potential of the solvent in the presence of solute.

[a]Required: at least to ask the question, and possibly answer it

References of Appendix I

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Appendix J. Bank of Texts That Can Be Used in Sessions of Education to Critique

This appendix presents a bank of texts that can be used as a resource for critical analysis education at different levels. The second column gives all the references to analyses or comments made in this book about them. Finally, the third column proposes a characterisation in terms of 'types of flaws' – reasons to contest an explanation – and/or' risk factors' – or reasons to be vigilant about the foreseeable effect on readers or listeners. Note also the frequent association, in the third column, of the type of fault "logical incompleteness" and the risk factor "a forgotten variable – or phenomenon", a case often related to the expression "abusive generalization". This is in line with the remarks made in Appendix A, echoing Duhem's "logical impossibility" (p. 60): the conclusions drawn from an experiment are always exposed to the risk of ignoring a variable relevant to the phenomenon under study.

Among the risk factors, a 'story-like ', or 'linear causal 'explanation is for us of the 'echo-explanation' type since it takes up a typical structure of common reasoning. To avoid redundant references, the table only mentions the other echo-explanations. In any case, the proposed categorisation can be discussed, the interest is above all to draw the attention of the trainer and/or the trainees to elements requiring clarification.

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
Two successive statements, validated by an entire class: 1- You can protect yourself from the cold with a survival blanket (debates and manipulations on heat conduction lead to statement 2). 2- With aluminium, you cannot protect yourself from the cold. *College class session, instructional video DVD.*	p. 11 Appendix B	Explicit internal incoherence associated with an abusive generalization: In statement 2, the radiative property of aluminum is ignored. *Only one variable considered and experimentally tested: thermal conduction*
Capillary rise and pressure difference at the air-water interface: '(...) the pressure immediately below the meniscus has a higher value than that of the atmosphere just above. It is this imbalance that explains the rise (...).' Further on: 'The smaller the tube diameter, the greater the meniscus curvature (...): according to Laplace-Young's law, the greater the water depression in the tube.' *Popular text.*	p.12 Appendix F	Explicit internal incoherence: the pressure under the meniscus is successively declared 'higher' and lower ('greater water depression') than that of the atmosphere. *Two linear causal explanations (one cause, one effect): in the first case, it would be a thrust which would explain the ascent, in the second it would be the meniscus which would have drawn the water (all the more so as it is more curved), thus creating a greater depression....*
'"Reaction can no longer balance Action.' *School Book*	p.13	Explicit contradiction of Newton's Third Law *Confusion between forces involved in a force balance (for one system) and those involved in an interaction (between two systems).*
'The force $\vec{F}$ exerted by the cyclist on the bike is directed according to $\vec{v}$ (bike velocity)' *Science book exercise (grade 12)*	p. 14	Indirect contradiction of a law: according to Newton's third law, the cyclist would then be pushed back and ejected from the bike. *Confusion between the person responsible for the movement of the bicycle and the external force acting on the cyclist-bicycle system.*
Radiocarbon dating: The ratio of $^{14}C/^{12}C$ concentrations in the atmosphere is stable over time. *Documents on the Internet*	p. 18 Appendix C	Logical incompleteness: how to explain that the ratio of $^{14}C/^{12}C$ concentrations in the atmosphere is stable over time, when we have just said that radiocarbon disintegrates spontaneously? *The possible intervention of other components in the atmosphere, which generate radiocarbon at the same rate as it decays, is not mentioned.*

(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
'In a transparent medium, such as glass for example, light propagates less quickly because its refractive index is higher than that of air'. *Popularisation brochure*	p.17	Logical incompleteness: this is a tautology since the refractive index n of a medium is defined by $n = c/v$, where c and v are the values of the speed of light propagation in vacuum and in the medium respectively.
'When the gas in the water comes into contact with clear limewater, it becomes cloudy. The limewater becomes cloudy in the presence of carbon dioxide. So the gas in the sparkling water is carbon dioxide.' *Current school use*	p.17	Logical incompleteness: the possibility of other causes producing the same effects is not considered. *Only one cause is considered*
Bernoulli's theorem illustrated via a cylindrical stream tube *Popularisation for training purposes*	Appendix D	Indirect contradiction of a law: for an incompressible liquid in steady state, there can be no acceleration in a cylindrical stream tube.
Bodies denser than water do not float. *Current statement*	p. 19	Logical incompleteness and overgeneralization *Only one variable is considered: what determines Archimedes' upthrust (beyond the density of water) is the displaced volume of fluid. This depends not only on the density of the body but also on its shape and the way it is immersed (see the case of boats).*
In a greenhouse, more energy enters than exits. *Common idea, common statement*	p. 20	Incompatibility with a thought experiment: this could not last. *Implicit story-like explanation (we follow the adventure of radiation). No distinction between the transient and the permanent regime, implicit centration on a transient regime.*
"In a gas, collisions between molecules produce heat" *Common idea*	p.20	Incompatibility with a thought experiment: this could not last in a thermally isolated chamber. *Implicit story-like explanation: the permanent regime is not envisaged in the long term.* *Designation of entities: meaning of 'heat'*

(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
To save energy, it is better to set the antifreeze protection at 10 °C than 4 °C, taking the cost of heating when you return into account. *Common idea*	p. 20	Incompatibility with a thought experiment; imagine a very long absence during a very long winter: the energy lost to the outside would clearly be greater with 10° inside than with 4°. *Implicit story-like explanation: focus on a transient*
Consider a pierced water bottle resting on a horizontal support. The maximum range, on the support, of a jet from this bottle is obtained with the lowest hole. *Numerous documents*	p. 21 Appendix E	Logical incompleteness Incompatibility with a thought experiment: the limit case of a hole at the level of the support *Only one variable is considered*: *the waterfall time is disregarded*
A battery in a closed circuit: the field in the wires is due to the charges on the poles of the battery. *Common idea*	p. 23 Appendix F	Indirect contradiction of a law: The wires do not necessarily have the bean shape of the field lines of a dipole. *One aspect of the situation is disregarded: the surface charges on the wire.*
'(…) the free electrons of the circuit are attracted to the positive terminal, repelled by the negative terminal of the battery. They circulate from the negative terminal to the positive terminal outside the generator.' *Common explanation*	p.23	Indirect contradiction of a law: The physical laws seem to be different inside and outside the battery. *In the absence of justification on the potential inside the battery, it is likely to be understood that negative charges, anions, are not subjected, locally, to a force opposite to the electric field that prevails at the point considered.*
'The experiment demonstrating the composition of air by Lavoisier' *A current school presentation*	p. 28	Logical incompleteness *Only one variable is considered: under the bell after oxidation of the mercury, there could be one or several other gas than the nitrogen.* *The accuracy of the conclusion: Lavoisier found an approximately correct result (we know now that other gases are present in the air, in small proportion).*
The isobaric hot air balloon *Common use in school and university exercises*	p. 29, 40	Explicit contradiction of the law of hydrostatics *The accuracy of the conclusion: with this hypothesis and Archimedes' theorem, we find a very acceptable value of the temperature necessary for take-off.* *Small assimilated to zero: pressure variations with altitude are very small but essential to lift.*

(continued)

Theme and possibly ‘text’ discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
‘From a given drop, only one wavelength reaches the observer’s eye’. *University course book*	p.30	*Designation of entities: shortcut and materialization of a concept (‘only one wavelength reaches the observer’s eye’).*
‘Pressure is a force distributed over an area’ *Popularisation book*	p.31	*Designation of entities: shortcut (A pressure is a force...) involving quantities that do not have the same dimension (same unit).*
‘Red pigment absorbs (all the) green light.’ *Common use in school books*	p.31	In case we think: ‘all the green light’: Incompatibility with a thought (or real) experiment *All or nothing. In fact, even with a very low diffusion coefficient, a pigment that receives intense monochromatic radiation diffusively reflects enough light so that the impact zone appears the colour of this light.*
‘Liquid water is non-compressible’ *Common use in school books*	p. 33	Incompatibility with a thought experiment (if nothing changes in the water at microscopic scale, how does the pressure change?), and with measurements. *Small assimilated to zero:* the coefficient of isothermal compressibility χ_T of water is non zero: $\chi_T = -(1/V)(\Delta V/\Delta p)_T = 4{,}4\ 10^{-10}\ Pa^{-1}$ *In fact 200 m below the water surface, the volume of one liter is 1 cm*^{3} *(order of magnitude) smaller than at sea level.*
‘In the absence of atmosphere’... a balloon in the stratosphere *A scientific journal article used for school purposes (grade 10)*	p.33	Explicit contradiction of the law of hydrostatics Incompatibility with a thought experiment: you cannot float without a surrounding fluid. The pressure at 40 km of altitude is very low but essential for lifting. *Small assimilated to zero*
Pascal has demonstrated the existence of a vacuum (by means of a tube turned over a container filled with mercury). *Current statement in school documents*	p. 33	Logical incompleteness: there could be an invisible substance at the top of the tube: Mercury vapour is not mentioned. *Small assimilated to zero*

(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
The interest, for a rocket, to take off from Kourou *School book (grade 9)*	p.33	Logical incompleteness *Only one cause is considered: the distance to the centre of the Earth. There could be (and there is) another concomitant cause: the rotation of the Earth.* *Accuracy of factual statements*
How can we explain the absence of atmosphere on certain planets? It is suggested that the low value of *g* is the cause of this phenomenon. *School book (grade 9)*	p. 34	Logical incompleteness *Only one cause is considered: lower value of g. There could be another concomitant cause: (e.g. larger value of the temperature).* *Accuracy of factual statements*
Floating wind turbines: hollow out the platform 'creates an Archimedes' upthrust'. *Radio broadcast*	p. 34	Explicit contradiction of the law of hydrostatics: in fact, as soon as there is submergence, there is an Archimedes' upthrust. *The effect of two causes (factors involved in the flotation: weight, Archimedes' upthrust) is attributed to only one: Archimedes' upthrust, which is nevertheless greater for a platform not hollowed out lying on the bottom of the water than for another of the same external volume, hollowed out, and floating..*
Water-filled test tube turned over on a tank full of water: 'What is lifting this column of water up by 2 m? It's atmospheric pressure that is pushing on the water in the container. In the tube, there is no air, and no pressure is exerted on the water'. *Marie Curie courses for children*	p.35	Indirect contradiction of a law: the atmospheric pressure that presses on the water in the container generates an upward force about five times the weight of the column. *Only one cause envisaged, only one place (at the bottom of the column) whereas there is repulsive interaction between the inside air and the top of the tube.* *Echo explanation: the weight of the water in the column would be equal to the action of this water on its support (the water in the tank), which is false.*
The Earth cannot exert a forward force on the pedestrian that accelerates forward because, at the same time, the support point is moving backwards. *Journal article on physics education*	p. 36	Indirect contradiction of a law: the pedestrian's center of mass accelerates horizontally, therefore the pedestrian at least undergoes an external force with a horizontal component in the direction of acceleration, which only the Earth can exert. *Echo explanation: a force should always be in the direction of movement of its point of application, which is wrong.*

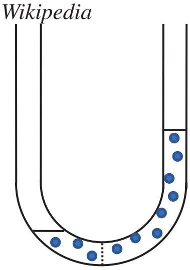
(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
Two springs in series hanging from the ceiling, pull down: 'the bottom spring stretches and after a while the second one too'. *Student's response (grade 10) to a survey*	p.39	Indirect contradiction of a law: in quasi-static analysis, the contact interactions at both ends of the springs have the same value. *Explicit story-like explanation (linear causal)*
In a gas: 'fewer molecules' means 'less pressure'. *Current statement, a popularization book*	p. 40	Logical incompleteness and overgeneralisation *Pressure is linked to a single variable, temperature is disregarded. Note that in a hot air balloon there are 'fewer molecules' (than if the air were cold) and there is no 'less pressure'.* *Echo-explanation: pressure seen as a compaction*
'By heating a gas, the pressure is increased', *or* 'Compressing a gas (increasing the pressure) increases the temperature', *or* 'Heating a gas increases its volume'. *Responses from university students during a survey*	p. 40	Logical incompleteness and over generalisation: other variables might affect the value of pressure. *In the triplet pressure, volume, temperature, each variable is linked to only one other and the statements do not specify what happens to the third one.*
Isobaric heating of an ideal gas: 'the temperature increases then the pressure will increase, therefore the volume too'. *Responses from university students during a survey*	p. 40	Explicit internal contradiction (see 'pressure will increase' while heating is said to be 'isobaric') *Explicit story-like explanation (linear causal)*
The siphon 'The water contained in the long branch of the siphon flows out. A vacuum is created and atmospheric pressure causes the water in the container in which it is immersed to rise in the small branch'. *Marie Curie courses for children*	p. 41	Logical incompleteness: there is the same atmospheric pressure value at the free surfaces of the water, in the tank as in the tube open downwards, so why would this pressure cause the water to "rise" and not "fall"? *Explicit story-like explanation (linear causal)* *Echo-explanation: an open branch downwards would necessarily let the water flow.*
'At the summit of Everest (8.848 m), air is becoming thinner: the Earth's attraction is only 9.760 N/kg instead of 9.811 N/kg at sea level'. *School book (grade 9)*	p. 41	Logical incompleteness: air would become thinner even with constant value of "the Earth attraction", on the other hand "the Earth attraction" does not depend on air density. *Echo explanation (suggestion of an improper relationship between density variation and variation of "the Earth attraction")* *Implicit meaning of ':'* *Accuracy of factual assertions*

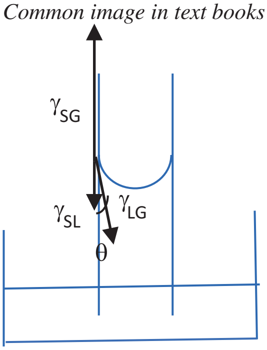
(continued)

Theme and possibly ‘text’ discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
An image to explain the Hall effect: the electrons are deflected and then return in the axis. *Image on Wikipedia in French*	p. 42	Indirect contradiction of a law: In steady state, electrons do not have a velocity component perpendicular to the edge of the sample. *Suggested story-like explanation (linear causal)*
Changes of state by exhaustion ‘By decreasing the temperature, the molecules have an average kinetic energy so low that they can no longer resist the electromagnetic attraction they exert on each other: they begin by agglutinating in the liquid state and end up binding in the solid state’. *University course book*	p.44 Appendix I	*Explicit story-like explanation (linear causal)* *Suggestion that:* *At thermodynamic equilibrium (also), the average kinetic energy per particle is less in the liquid than in the gas. Hence there is a risk of contradiction of physical laws: In fact, the average kinetic energies at equilibrium between phases at given T are equal.* *Metaphorical language* *Also: If molecules can no longer resist, how can the pressure remain positive?*
The rays seen with a magnifying glass *Image in university course*	p. 47	*Realism v/s Symbolism* *Echo-explanation (light would be visible in profile)*
Sunbeams and lines of sight University course book	p.49	*Similarity of symbols used for different entities* *Echo explanation*
Young’s holes that deviate light rays *Image of current school or university use*	P. 50	*Similarity of symbols for different entities (before and after the hole)* *Selection of the elements represented* *Story-like explanation (suggested: the ray continues its adventure)*
Colour syntheses *Commonly used image*	p.51	*Similarity of symbols used for different entities* *Overselectivity of the elements represented* *All or nothing*
Aliens and the size of the Earth *Proposed image for school use (grade 10)*	p.52	Indirect contradiction of a law (what about the size of the Earth on the image whereas it is so far away?) *Image structure and scales of representation*

(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
'The cosmic fossil radiation, which the expansion of the universe abandoned on the side of the road about ten billion years ago, and which has since bathed interstellar space without interacting with matter (...) it was discovered by chance in 1964 by two radio astronomers who were looking for something else'. *Popularisation book*	p. 53	Explicit internal contradiction (radiation detected without interacting with matter) *Explicit story-like explanation* *Metaphorical style*
Osmosis leads to an equilibrium with the same solute concentrations and different pressures on either side of the membrane: 'Since everything happens as if the membrane does not exist for the solvent, a situation of imbalance will be created (...) the passage of the solvent taking place until a new equilibrium is established (minimum free energy), therefore when the concentrations in A and B will become equal. There will thus be a difference in level between the compartments (...), therefore a difference in pressure $\Delta p = pA\text{-}pB$, (...) which is called osmotic pressure.' *University course book, similar diagrams on Wikipedia*  Semi-permeable membrane Final state	p.57, 77 Appendix I	Indirect contradiction of a law Contradiction with two thought experiments (starting with pure water on one side only: one would then have an endless migration of pure water towards the solution; comparing the balance with the same concentrations and pressures on each side of the membane and that described by the text. *Only one cause (only one variable) is considered* *Explicit story-like explanation* *(Iconic aspects could be criticised but are not essential here)*

(continued)

Theme and possibly 'text' discussed *Type of document*	References in the book	Type of flaws *Type of risk factor*
The capillary rise and the angle of contact: the force that 'lifts the liquid' *Common image in text books*  	p. 78 Appendix G	Indirect contradiction of a law Logical incompleteness (Balance of horizontal forces? What about the weight of the column?) *Accuracy of conclusion* *A single place (of action of the forces: 'above') is considered* *Overselectivity of the schema (on what objects do the forces act?)* *Metaphorical style (the force "lifts" the liquid)*
To protect yourself from the cold with a survival blanket, you must put the silver side inwards to reflect the heat back towards you. *Common idea* *Instructions for use on products and internet documents*	p. 75 Appendix B Appendix H	Logical incompleteness: what about the radiation of the blanket towards the outside? *Explicit story-like explanation,* *Only one location envisaged (between the body and the cover, and not between the cover and the outside).*
The unfortunate Captain Haddock: the asteroid Adonis attracts him.... *Hergé*: *We walked on the moon*	p. 85	Indirect contradiction of a law: why would Captain Haddock's trajectory be more deviated than that of the rocket whose engine is off?