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**Enseignement**

# Methodological advances in scientific publication

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**Résumé :**

Un article où Antoine Laurent de Lavoisier présente ses résultats sur la confection des bouillons de viande est l'occasion de mieux voir les progrès méthodologiques effectués en communication scientifique par les sciences de la nature. C'est également l'occasion de discuter la question de "bonnes pratiques scientifiques".

**Abstract:**

An article in which Antoine Laurent de Lavoisier discussed his results on the making of meat broth is an opportunity for evaluating the methodological advances proposed for the communication of research results in the past centuries by sciences of nature. It is also the possibility to discuss the issue of "best practices" in science communication.

**Keywords:**

method, best practice, natural sciences, history, publication

**Mots clefs :**

méthode, bonnes pratiques, sciences de la nature, histoire, publication

**Introduction**

In this article, we focus on a text (Lavoisier, 1783) published by Antoine Laurent de Lavoisier (1743-1794), the father of modern chemistry (Gillispie, 1970; Crosland, 1978), who was (among other honors) a member of what became the Académie d'agriculture de France (Académie d'agriculture de France, 2016). The goal of our article is certainly not to criticize Lavoisier or the scientific work that he describes, because he did more than his contemporaries, being able to extend the realm of knowledge more than others did at his time. Indeed we use his publication for two reasons: firstly it is a way to better appreciate the methodological advances in the communication of the results of natural

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sciences; and secondly this analysis gives the opportunity to admire the contribution of Lavoisier to the study of aqueous solutions obtained by the thermal processing of animal tissues in water ("meat broth").

More precisely, aiming at better understanding the rules of best practices in science communication (This, 2015), we shall discuss less the scientific results than the way Lavoisier communicated them, at a time when there was no "Guide to authors" given by scientific journals. We have the feeling that such a discussion can be useful for science education, showing how the scientific communication methods have been improving since two centuries. Seldom was the idea that we are dwarfs on the shoulders of giants more appropriate than here.

### The Memoir and its commentaries

In all this text, the excerpts by Lavoisier (shortened L.) are in italics, in boxes that separate the original article from commentaries, in roman. These commentaries are restricted to the methodological issues, but sometimes they give information in order to appreciate the scientific question discussed by L. The original text of L. is translated personally, and the original French text is given in footnotes.

*Memoir on the strength that meat broth should have, on their specific weight and the quantity of gelatinous matter that they contain.*<sup>1</sup>

This article was published in November 1783 (Lavoisier, 1783). At that time, L. was 40 years old. He was already a full member of the French Royal Academy of Sciences and "fermier général" (tax collector). On the painting

<sup>1</sup> *Mémoire sur le degré de force que doit avoir un bouillon, sur sa pesanteur spécifique et sur la quantité de matière gélatineuse solide qu'il contient*

by the French painter Jacques-Louis David (Figure 1), he appears with his wife Marie-Anne Pierrette (born Paulze), who participated to his scientific works (Poirier, 1993).



*Figure 1. Antoine Laurent de Lavoisier and his wife, painted by Jacques Louis David.*

Concerning the title of the article, one can observe that it is a good practice to use previously defined words. As a consequence, today's reviewers have a duty to check that no ambiguous word or expression remains in the manuscript: their remarks help the authors to improve their text, and sometimes even their work, making complementary experiments, validations, etc.

In this regard, "broth" could either be "the aqueous solution obtained by thermal processing of muscular tissues of animals", or a solution obtained from both muscular tissues and bones. It will be shown later in the memoir

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that the first option holds. As well, "meat" is more precisely defined as "muscular tissue", and even more precisely the tissue from *Bos taurus*. Later in this article, we shall use "meat broth" for "aqueous solution obtained by the thermal treatment of muscular tissue of *Bos taurus*".

Moreover today "density" would be used instead of "specific weight", as the International System of Units should be used (IUPAC, 2016), in part due to efforts of L. shortly after the French Revolution ("metric system").

*The Royal Society of Medicine was consulted by the Secretary of Navy about the diet that patients should have in hospitals, and it appeared, in many discussions about this question, that we were lacking precise information on the nature of the broth that is given to patients, on the proportion of water and meat that should be used for making such broth, on the quantity of gelatinous or extractive matter that they contain, on the differences that are due to the different qualities of meat, on the degree of concentration that the broth should have depending on the various states of sickness, and finally how the quality of broth can be recognized.<sup>2</sup>*

<sup>2</sup> *La Société royale de médecine ayant été consultée, par le ministre de la Marine, sur le régime qu'on doit faire observer aux malades dans les hôpitaux, s'est aperçue, dans les conférences nombreuses qui ont été tenues à cet effet, qu'on n'avait pas de connaissance assez précise sur la nature du bouillon qu'on donne aux malades, sur la proportion d'eau et de viande nécessaire pour le composer, sur la quantité de matière gélatineuse ou extractive qu'il contient, sur les différences qu'apportent dans sa qualité les différentes espèces de viandes ; sur le degré de force que doit avoir le bouillon, suivant les différents états de maladie ou de convalescence ; enfin, sur les caractères au moyen desquels on peut reconnaître sa qualité.*

The Royal Society of Medicine was the equivalent of the current National Academy of Medicine (Lavoisier, 1789), of which L. was also a member. It can be observed with L. first paragraph that at the time of L., very few references were given in scientific articles. Today, any proposal, any idea, any fact, any information have to be justified by literature references or by experimental data, along with information on how these experimental data were produced (ESF, 2000).

Finally, concerning the work on broth, the question proposed in this introduction is simple only in appearance (This and Bram, 1998): L. wanted to explore the proportion of water and muscular tissue that one "should" use in order to make meat broth. What does "should" mean? It was precisely the question asked by the ministry: how to define the diet.

Indeed meat broth is a traditional preparation of great importance for ancient diets: recipes for broths were generally given at the very beginning of culinary books (Passiranus, 1497; La Varenne, 1651; Menon, 1756; Carême and Plumerey, 1705) and they were considered as very important for invalids or people recovering from disease.

However a special care is needed about expressions such as "one should", "it is convenient", "it is necessary", or "one has to". From a technical point of view, meat broths can be obtained from any proportion of muscular tissue and water, but it is true that strongly diluted broth would not be "convenient" for human health, because they would lead to overconsumption of water, if enough nutrients are to be obtained. Anyway reading carefully L.'s article shows that the text refers implicitly to a sensory standard. Such a standard is not easy to define, as food cultures are diverse, and sensory appreciations depend on culture, as well as physiology (William, 2006).

Moreover L. immediately makes a link between this "necessary proportion" and a quantity of "gelatinous or extractive matter".

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We know today that it is true that, during broth making, the muscular tissue (sometimes along with bones, for stocks) is releasing in water various mineral and organic compounds, some of which being responsible for broth gelling after cooling (Lémery, 1705; Wandsnider, 1997).

More precisely, in muscular samples, collagen tissue is around individual muscular fibers as well as grouping individual fibers in bundles and super-bundles (epimysium, perimysium, endomysium). It is now known that collagen tissue is made from the protein collagen, i.e. trimers of polypeptide chains (Girard, 1998). During thermal treatments, the collagen tissue is disrupted, and collagen is dissociated and partially hydrolyzed, forming peptides of various lengths from one free amino acid to very long chains (Listrat and Hocquette, 2004). The material obtained by purification and drying is called "gelatin", but one can see that this word is ambiguous, because it describes various products, depending on the purification processes that are performed during production.

When the temperature of a solution of gelatin or of a broth (containing gelatin as well as many other compounds extracted from meat) is reduced, the dissolved polymers can re-associate by their ends (Djabourov, 1986), forming a three dimensional network to which water is bound (IUPAC, 2015). There are different kinds of gels but gelatin gels have a DSF ("disperse system formulism) formula (This, 2013) defined as  $SxW$ , where S stands for the solid network, W for the aqueous solution, and the symbol "x" describes the intermixing of two continuous phases.

For the sake of the current discussion, let's say that gelatin is not the sole matter extracted from meat (Wright, 1910; Maikhuntod, 2005). Peptides and amino acids formed from collagen (Rogalinski et al., 2005) are "extracted" as well, but they are not "gelatinous" in the meaning of being able to contribute to the gel formation (Chemguide, 2015). Moreover other organic

and minerals compounds move from the muscular tissue to the solution, so that one should distinguish "extracted matter" and "gelatinous matter". Also one should make a difference between the extractable matter, i.e. the total content of compounds that could be extracted from the muscular tissue (and dissolve in water or evaporate) when the thermal treatments are longer than those that are practiced by the chefs (some hours) (Carême, 1705), and the extracted matter, which is indeed extracted (a fraction of the previous one). Of course, L. could not know all this, because chemistry at that time ignored molecules, proteins, amino acids, etc. (Jacques, 1987)

*One cannot avoid being surprised, each time one thinks of the most familiar objects, of the most trivial things, to see how our ideas are often vague and uncertain, and how, as a consequence, it is important to fix them by experiments and by facts.<sup>3</sup>*

This sentence is particularly important, as it states correctly that scientists have to avoid vague discourses. Sciences advance through unambiguous descriptions, experiments, measurements and precise determinations, including other tasks (This, 2009).

*In 1730, M. Geoffroy communicated to the Academy of Sciences his results on the same topic, but as his goal was different from mine, we did not use the same methods, and we cannot compare the results. This chemist wanted to know, using*

<sup>3</sup> *On ne peut s'empêcher d'être surpris, toutes les fois qu'on s'interroge soi-même sur les objets qui nous sont les plus familiers, sur les choses les plus triviales, de voir combien nos idées sont souvent vagues et incertaines, et combien, par conséquent, il est important de les fixer par des expériences et par des faits.*



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*chemical analysis, the nature of nourishing substances, either animal or from plants. In the experiments he did on meat, he boiled them successively in many solutions, starting each time from pure water, until the meat did not release any matter. He then evaporated the water from all the solutions, and obtained separately all the gelatinous and extractive matter that was contained initially in meat.*<sup>4</sup>

Again modern scientific journals would include references for the various sentences. In particular, the reference to the work of M. Geoffroy would be useful, as this missing information makes it difficult today to know who exactly "M. Geoffroy" was. It could have been Etienne François Geoffroy, also called Geoffroy l'Ainé (Paris, 1672-1731), or Claude Joseph Geoffroy, called Geoffroy le Cadet (Paris, 8 août 1685 – Paris, 9 mars 1752), or his son Claude François Geoffroy (1728-1753), who succeeded him and was elected to the Academy of Sciences in 1752 (Geoffroy, 1733). Historical research is needed to know that L. refers to Geoffroy le Cadet (This and Bram, 1998).

Finally let's observe that L. makes correctly a difference between science and technology: natural sciences are looking for the mechanisms of phenomena (This, 2009),

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*4 M. Geoffroy a communiqué à l'Académie des sciences, en 1730, un travail sur le même objet ; mais, comme son but était différent du mien, nous ne nous sommes rencontrés ni dans les moyens, ni dans les résultats. L'objet de ce chimiste était de connaître, par l'analyse chimique, la nature des différentes substances nourissantes, soit animales, soit végétales ; en conséquence, dans les expériences qu'il a faites sur les chairs des animaux, il les a successivement fait bouillir dans un grand nombre d'eaux différentes, qu'il renouvelait jusqu'à ce que la viande fût entièrement épuisée de toute matière extractive ; alors il faisait évaporer toute l'eau qui avait passé sur la viande, et il obtenait ainsi séparément toute la parties gélatineuse et extractive qu'elle contenait.*

whereas technology aims at improving technique.

*My goal, on the contrary, was to get purely practical knowledge and to determine what meat can release to some precise quantity of water, through a slow and long boiling process, instead of what it contains, concerning the gelatinous and extractive matter.*<sup>5</sup>

L. explains well that his study is of technological nature: the question is to produce broth, and to improve broth production. He is not interested in this article in the composition of meat, but only in the techniques implemented in broth production. Anyway it can be observed that his results could have been improved when he had made a difference between the content in "gelatinous and extractive matter" and when he had explored the duration of the thermal process, as proteins hydrolysis increases the quantity of the "part given to water". Today, we would observe that such differences can be made more easily if adjectives and adverb ("slow", "long"... ) were replaced by the answer to the question "how much?". This sole observation shows not only how scientific communication improved, but also how scientific research evolved, when the true nature of science was more clearly defined (This, 2009).

*In order to get some information on the most convenient proportion of meat and water, according various cases, I produced broths*

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*5 Mon objet, au contraire, était d'acquérir des connaissances purement pratiques et de déterminer, non ce que la viande contient de substance gélatineuse et extractive, mais ce qu'elle peut en communiquer, par une ébullition lente et longtemps continuée, à une quantité donnée d'eau.*

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*changing the doses, from 4 onces per pound of water [4. 30.59375000 = 122.3750000 g], up to one pound of water per pound of meat.<sup>6</sup>*

Here, in the original text, a calculation is added between brackets: in our own text, the eighteenth century units were translated into modern units (g). The results of calculation are in brackets, and the number of digits given is always (arbitrarily) chosen to be 10, because there is no way to determine how much it is really, from the original text. Accordingly one should not consider that the figures given are significant, as it is the modern rule.

In order to translate the units, official data are used (Métrologie française, 2016) as well as intern validations (the French rule is not followed, however, concerning the use of commas and dots; instead the English rule is applied for separating the integer part and decimal digits): later in the text, it is explained that 0.5 "livres" (the English word could be "pound", but the word "livre" will be kept because it is not the same as the current English pound) corresponds to 8 "onces". The livre of Paris, before the 7 April 1795, was equal to 489.5 g. It was divided into 16 onces of 8 "gros", each gros being equal to 72 "grains":  
1 livre = 489.5 g;  
1 once =  $489.5/16 = 30.593375000$  g;  
1 gros =  $30.593375000 / 8 = 3.824218750$  g;  
1 grain =  $3.824218750 / 72 = 0.05311414931$  g.

*I say in advance, once for all, that whereas my experiments were done with large quantities, I decided to display the results with a common reference because I wanted to facilitate comparisons; I calculate for one livre of broth the results that I am presenting.<sup>7</sup>*

<sup>6</sup> Pour acquérir d'abord des connaissances sur la proportion de viande et d'eau la plus convenable suivant les différents cas, j'ai fait différents bouillons en variant les doses, depuis 4 onces par livre d'eau jusqu'à livre pour livre.

Again, the word "large" (adjective) could have been usefully replaced by quantitative information. Because of the particular style of scientific writing in the eighteenth century, the calculation that L. is announcing is creating doubts concerning the use of significant digits. Indeed let us assume that L. considered 3 livres of broth, where he would measure 20 g of "extractive matter" (precision 1 g). If he had divided by 3, he would have obtained  $20/3 = 6.6666666667$ , with 10 significant numbers, which is not fair, as he could not know the value with a precision higher than 1 g.

More generally, a big advance in science and science communication was performed when a clear use of significant digits was introduced. Let us also observe that today's scientific journals are calling for statistics, which were not available at that time (for example, the Student test was introduced only in 1908 by the British statistician William Sealy Gosset (1876-1937))(Pearson, 1990).

*I first observed that one livre of broth, prepared from one livre of water [489.5 g] and 4 onces [ 30.59375000. 4 = 122.3750000 g] of meat produced a very weak broth, whose specific weight was, relative to water, in the ratio of 1002322 to 1000000; by evaporation, one could recover only 35 grains 1/2 [35.0.05311414931 = 1.885552301 g] of gelatinous matter after reduction to stock tablets. I used thick flank in this experiment and in the two next.<sup>8</sup>*

<sup>7</sup> Je prévins d'avance, une fois pour toutes, que, quoi que mes expériences aient été faites en assez grand, j'ai cru, pour les rendre comparables, devoir les ramener à une mesure commune, et en conséquence, je réduirai par calcul à une livre de bouillon les résultats que j'aurai à présenter.

<sup>8</sup> J'ai d'abord reconnu qu'une livre de bouillon, faite avec une livre d'eau [489.5 g] et 4 onces de viande, ne formait qu'un bouillon très-faible, dont la pesanteur spécifique était, à celle de l'eau, dans le

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The only thing that one can know for sure from this paragraph is that a broth was prepared with 1 part of meat for 4 parts of water, and that it was "weak". Why did L. choose this particular proportion? In a modern scientific article, this would be explained, and the adjective "weak" would be defined, preferably quantitatively when possible.

Also it is not said which animal tissue was chosen, and this is the opportunity to observe that scientific advance since the eighteenth century makes it possible to be more precise, using the international rules: today the imprecision of "thick flank" would be avoided by the use of *obliquus extremus*, or *pinalis gracilis*, *quadriceps femoris*, *semimembranosus* (Delmas, 2006).

Was the meat cut parallel to muscular fibers, or transversally? This could be important, as the release from the muscular fibers could be modified when the fibers are open. From which animal was the meat: which variety, sex, age, breeding conditions, slaughtering conditions, maturation? We know today that all this is important for the quality of meat broth.

Today's "Materials and Methods" sections would also include a description of the preparation of the broth. Was the meat put in hot or in cold water (the coagulation of proteins at the surface could change the extraction)? Was the pot covered by a lid? How long was the meat thermally processed in water?

For masses, the precision with which they were measured would also be given in the "Material and Method" section. About this particular aspect of the work, it has to be observed that L. is known for being one of the first to have used extensively weighing scales in chemistry (Gillespie, 1970), and the scales he used were very precise (as can be observed in the article

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*rapport de 1002322 à 1000000, et qu'on en obtenait, par évaporation seulement 35 grains 1/2 de matière gélatineuse réduite à la consistance de tablettes de bouillon. C'est de la tranche qui a été employée dans cette expérience et dans les deux suivantes.*

that we discuss here, see below); the "Fortin scale" that we know L. was using for some researches could measure masses with a precision of 25 mg for a mass reaching 10 kg (UQAC, 2015).

Based on advances due to L., new best practices were later introduced. Today the weighing scales have to be controlled and checked regularly, and at least three measurements have to be made for each sample (in order to calculate a standard deviation). Modern "Materials and Methods" would also include indications that samples are cooled down to "room temperature" (to be more precise) before weighing because hot samples can heat air around, so that the sample are sucked upwards, giving wrong results (AOAC, 2016). Finally, today different scales (described by name of brand, model, precision, etc.) would be probably used for large (~ 1000 g) and small (~1 g) masses, because of ISO rules about mass measurement, so that different significant figures would be given (Radwag, 2016).

*Table 1. Variation of the density of water in function of temperature.*

Temperature	Density
5	1.000
10	1.000
25	0.999
20	0.998
25	0.997
30	0.995
35	0.993
40	0.991
50	0.990
65	0.980



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For density, there is also a question of significativity of figures. Without a "Materials and Methods" section, one cannot guess if the 7 figures displayed by L. are really significant. This is very important, as the density of water (and broth) changes with temperature, as shown on Table 1 (ASCE Manuel 25, 1995). Using these data, one can see that the difference of density of water is changing by more than

$$100. \frac{0.988 - 0.980}{\frac{1}{2} \cdot (0.988 + 0.980)} = 0.81200081301 \quad \%$$

between 20 °C and 65 °C, for example: in other words, the densities can be wrong after the third digit if the density measurements are not performed at the same temperature. This is important, because mass measurements are not always performed in temperature controlled rooms, and the temperature changes by more than 1°C during a day (the sole presence of scientists in rooms can increase the temperature), one can calculate that, at best, the density of broth could be determined with a precision of  $0.001/3 = 0.000333333333$  (indeed this should be written 0.0003) at "room temperature", if best practices for mass measurement were applied.

By evaporation, one would have obtained about 2 g of solid matter, but the remaining doubt about L.'s practice would be suppressed with modern methods. In passing, it can be observed that one cannot be sure about the nature of these 2 g: L. writes "reduced to the consistency of meat tablets", but this is not clear, because it could depend on how the broth was "reduced" to tablets, and how much water remained in these tablets. What are "tablets", indeed? According to culinary books of the time, they are gels obtained by a slow drying of broth, but this is not enough as different temperatures and air humidity can lead to different equilibrium, so that different quantities of water remain in the final product. Today, the "Materials and Methods" section would include a paragraph defining tablets or

giving information on how much water such tablets can keep (after some particular analysis).

*One livre of broth prepared from 8 onces or one 'demi-livre' of meat [489.5/2 = 244.7500000 g], had a specific weight of 1003080; evaporation reduced the mass to 47 grains ½ [47.5 . 0/05311414931 g] of gelatinous matter reduced to a consistency of tablet. This broth could be considered as weak, but enough for sick people. Finally one livre of broth made from one livre of meat had a specific weight of 1007347; it was strong and delicious, and its masse was 116 grains [116 . 0.05311414931 = 6.161241320 g] after reduction to dry gelatinous substance.<sup>9</sup>*

The same observations as before can be made here, but as the adjective "delicious" is added to "weak" or "strong", an interesting question arises, as how such broth would be appreciated today. The question is important, as the history of cooking shows that recipes evolved with time: for example, at the beginning of the twentieth century, custards were made from 16 egg yolks (*Gallus gallus*) for 1 L of milk (Gilbert et al., 1901), but today only 8 yolks are used for the same quantity of milk (Cardinale et Van Sevenant, 2010). Let us observe that, for a modern article, the description could be usefully given in a table (Table 2).

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<sup>9</sup> *Une livre de bouillon dans lequel il était entré 8 onces ou une demi-livre de viande, s'est trouvée avoir, pour pesanteur spécifique, 1003080 ; il a laissé, par évaporation, 47 grains ½ de matière gélatineuse réduite à consistance de tablettes. Ce bouillon pouvait être encore regardé comme faible, mais suffisant cependant pour le cas de maladie. Enfin une livre de bouillon, formé avec une livre de viande, avait pour pesanteur spécifique 1007347 ; il était fort et succulent, et a laissé par évaporation 116 grains de substance gélatineuse desséchée.*

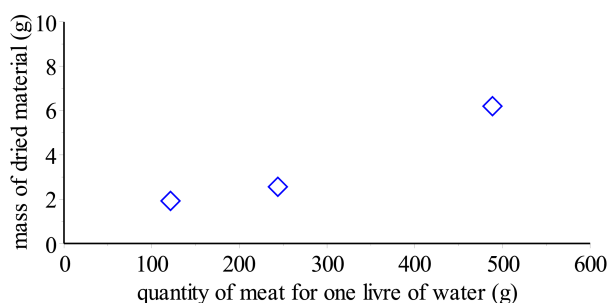
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Table 2.

Quantity of water (g)	Quantity of muscular tissue (g)	Mass of gelatinous substance (g)
489.5000000	122.3750000	1.885552301
489.5000000	244.7500000	2.522922092
489.5000000	489.5000000	6.161241320

Such a table is more succinct, but it can be even improved by transforming tables in diagrams, avoiding methodological pitfalls that we shall now consider.

Let us begin with a "naive" display (Figure 1).



*Figure 2. A naive display of data: the size of the symbols is arbitrary, and this is not said.*

In this bad picture, nothing is said of the size of displayed symbols: it is a good practice that this size takes into account experimental uncertainties or standard deviation based on more 3 measurements (Harris, 2010).

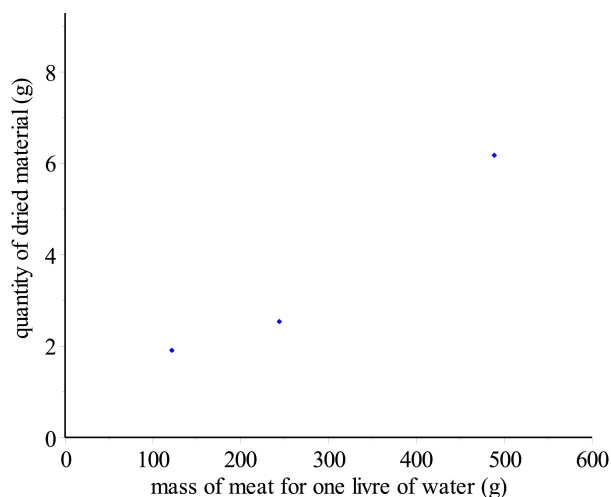
Here let us assume that L. did not divide his data in order to compare to 1 livre, and that data are really the one he could measure. We observe that he announces values down to 1/2 grains, i.e.  $0.05311414931/2 = 0.02655707465$  g; this should be written: 0.03 g.

In other words, the previous table should be given as Table 3.

Table 3.

Quantity of water (g)	Quantity of muscular tissue (g)	Mass of extracted substance (g)
489.50	122.38	1.89
489.50	244.75	2.52
489.50	489.50	6.16

The experimental results should be shown as in Figure 3.



*Figure 3. The size of symbols is based on the determination of measurement uncertainties.*

In particular it can be observed that the size of symbols in Figure 2 was too big. In Figure 3, it is correct, and the caption should say something about the relative sizes of uncertainties and displayed dots.

*These first experiments taught me three things:*

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1. *the convenient proportion for making broth being used for sick people is about two parts of water for one part of meat ;*<sup>10</sup>

Again, with the word “convenient”, we can observe that the scientific work and communication are improved when adjectives and adverbs are replaced by quantitative information. It is doubtful if “convenient” is culturally defined in terms of flavour (This and Gagnaire, 2010). Another interpretation of “convenient” could be in terms of nutrition, as broth and meat tablets were considered as nutritionally important in the eighteenth century (This, 2008). It could be also a question of cost effectiveness: L. seeks the healthiest broth and a solution the hospital can afford since they need huge quantities of broth.

2° *that there is a quite exact ratio between the quantity of gelatinous substance in the broth and the specific weight, so that one can determine one from the other;*<sup>11</sup>

Here again, the adverb “quite” is ambiguous, and giving a quantitative estimation of the ratio is better. Moreover a non established fact is given. Indeed the “proof” of it is given later in the text, but the impression that a non-proved fact was introduced would be avoided today with the general structures of articles, made of (1) Introduction, (2) Materials and Methods, (3) Results, (4) Discussion, (5) References. Without looking further at L.'s text now, let us try to determine the announced ratio quantitatively, using the diagram of the density

<sup>10</sup> *Ces premières expériences m'ont appris trois choses : 1° que la proportion convenable pour faire du bouillon à l'usage des malades est d'environ deux parties d'eau contre une de viande ;*

<sup>11</sup> *2° qu'il existe un rapport assez exact entre la quantité de substance gélatineuse contenue dans le bouillon et la pesanteur spécifique, de sorte qu'on peut conclure l'une de l'autre ;*

in function of the quantity of gelatinous substance, assuming that this quantity was correctly determined (Figure 4).

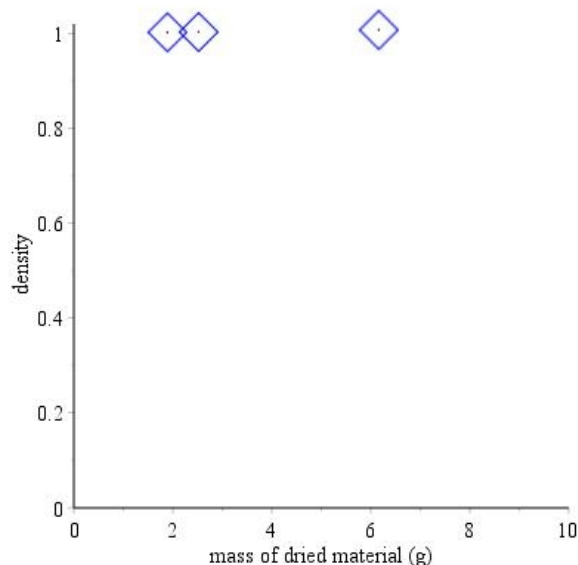


Figure 4. *The density of broth in function of the mass of extracted matter. The size of symbols is arbitrary.*

Here the size of the symbols on the diagram was arbitrarily chosen, because we do not know the uncertainty on density, as no clear information is given (at this stage of L.'s text) on how he made the measurements. As values such as 1.002322 are displayed, we should (today) think that the last digit is significant.

It should be added that the display is only an illustration of the calculus of the ratio of the dried matter by the density. For the 3 measurements, the ratios are 0.5303291005; 0.3980476190; 0.1635303571. This calculation does not show the announced constant ratio, strictly speaking. At this point, we can add that things would be clearer today, as advances in mathematics would lead to give a different name to proportionality ( $y = kx$ ) and affinity ( $y = a x + b$ ). Let us look, for example, whether the

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experimental data are along a line, calculating a regression line (Harris, 2010). For such a regression, it is a good practice to calculate both the correlation coefficient and the residues, i.e. the differences between the fitted line and the experimental data. Again we have to decide how to display the results. On Figure 5, we purposely gave a bad display of data (Tufté, 1985).

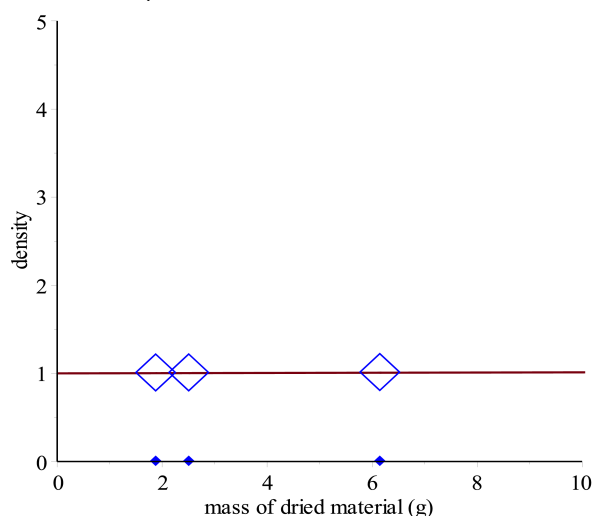


Figure 5. On this purposely wrong display, the data and the residues (difference between fitting and data) are simultaneously shown.

Here, the equation of the fitted line obtained by linear regression is  $1.00010887964955 + 0.0011752472443 x$ , with a correlation coefficient equal to 0.9999946264. On Figure 4, the range used for ordinates is compressing both residues and the fitted line. It would have been better to use two different scales, or to make two different displays (Figure 6). On Figure 6a, it is now easier to see a "quite exact" ratio or more precisely a "good" fitting by a linear relationship. More precisely, the residuals are less than 0.05 and the correlation coefficient is almost equal to 1... which is strange, when one considers the difficulty of making precise measurements of density. It is true that, having this fitting, the abscissa can be determined from the ordinates, or vice versa... but the question of uncertainties remains.

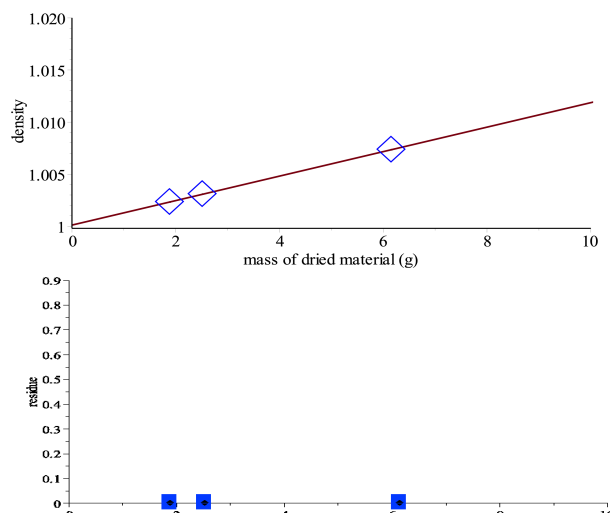


Figure 6. (a) Density in function of the mass of dried material. (b) Residues obtained by fitting.

It is true that, having this fitting, the abscissa can be determined from the ordinates, or vice versa... but the question of uncertainties remains.

3° that when meat is boiled in a large quantity of water, more extractive matter is extracted proportionally, than when meat is boiled in a small quantity of water. It was observed indeed that 4 onces of meat led to 35 grains 1/2 of gelatinous matter; a livre, in this proportion, would have given 142 grains, but only 116 grains were obtained; about one sixth can be recovered more when boiling with a large quantity of water.<sup>12</sup>

12 3° qu'en faisant bouillir la viande à grande eau, on extrait, proportion gardée, plus de matière extractive que quand on la fait bouillir à courte eau. On a vu, en effet, que 4 onces de viandes ont donné 35 grains 1/2 de matière gélatineuse, ; une livre, dans cette proportion, aurait dû donner 142 grains, et cependant on n'en a obtenu que 116 ; il y a donc un sixième environ à gagner à faire du bouillon à grande eau.



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Now there is the question of the non linearity of extracted matter in function of the proportion of water and meat. Again the display of the Figure 6 is bad, because symbols seems on a line, but the eye cannot distinguish correctly a possible non linearity; calculating a coefficient is more appropriate.

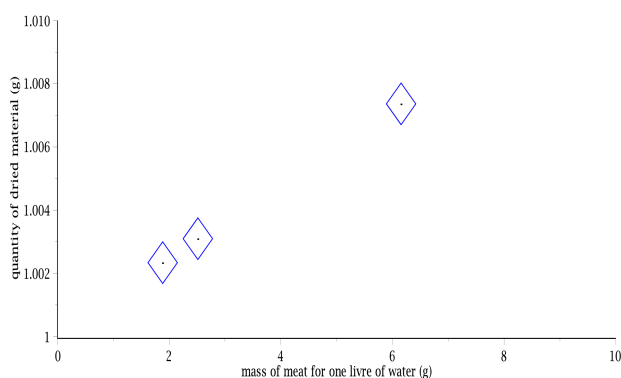


Figure 7. On this figure, the trend followed by experimental data is not easy to detect.

The Figure 8, where the abscissa range was reduced, shows better the variation of the quantity of dried matter in function of the proportion of meat.

Now it appears more clearly that the ratio of the mass of extracted matter by the mass of meat is not constant. Indeed L. himself, later in his memoir, proposes a way of calculating the variations, using first differences and second differences (Piskounov, 1980). Here we could compare the slopes of lines going through the first two dots, and by the last two dots:

$$C1 = \frac{Mg[2] - Mg[1]}{Mv[2] - Mv[1]} = 0.005148320667$$

$$C2 = \frac{Mg[3] - Mg[2]}{Mv[3] - Mv[2]} = 0.01487232869$$

The slope increases by 65.4 %: this is more than half the value, so that L. (assuming again that the uncertainty issue is solved) was indeed allowed to write what he wrote (it would be better to say how much, anyway).

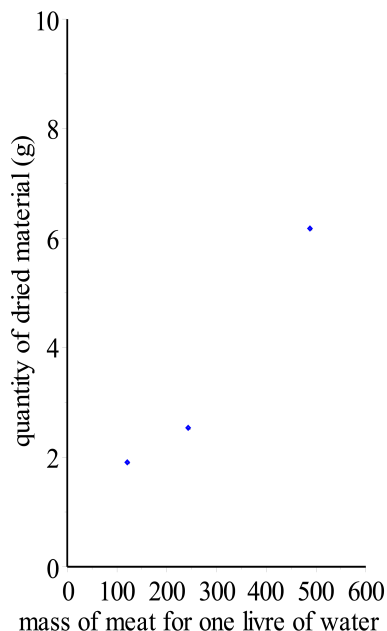


Figure 8. On this figure, the trend followed by experimental data appears better.

*After having observed what the proportion of water and meat was roughly necessary to make the broth of hospitals, I wanted to examine if the different kinds of meat would make differences on strength and quality of broth.<sup>13</sup>*

Here, an inter-title would be useful, as a new result is given. Some scientific journals allow the authors to use such subdivision. This is not a detail, as scientific publications have the duty to communicate clearly the ideas. On the other hand, the goal of the work is clearly said by L.

<sup>13</sup> *Après avoir reconnu quelle était, à peu près, la proportion de viande et d'eau nécessaire pour former le bouillon d'un hôpital, j'ai voulu examiner si les différentes espèces de viandes apporteraient de grandes différences dans la force et dans la qualité du bouillon.*

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*As a consequence, I used one livre of the different pieces of beef meat: the meaty part of legs; the meaty part of butt; brisket; cheek; outside flat, which is considered to be the best for broth making; neck with bone; part of blade, i.e. shoulder; round; rib; hindquarter flank: these are cartilaginous parts at the anterior part of brisket, at the end of ribs.*<sup>14</sup>

It is only here, well behind the first results, that L. indicates that he used muscular tissue from *Bos taurus*. However some uncertainty remains, because it is not sure that the old names for meat pieces are the same as today, as said before. This gives another opportunity to see how the methods for scientific communication improved and why the works of the *International Union of Pure and Applied Chemistry* and from other standard agencies (*Bureau international des poids et mesures, Agence française de normalisation, Association of Official Agricultural Chemists*, etc.) are useful for proper scientific communication: today there would be less ambiguity, because the usual French names would be explained by international Latine names. Of course, the sole existence and usefulness of such institutions calls for proper information of students, during their studies (Boesdorfer, 2015).

*All the meats were deboned, except for the neck, and they were cooked in water for seven to eight hours, in simmering conditions; the dimensions were chosen so that two livres*

14 *J'ai pris, en conséquence, une livre des différentes espèces de viande de bœuf ci-après, savoir : du trumeau, qui est le jarret ; de la culotte, qui est la partie charnue des cuisses ; de la poitrine ; de la joue ; du gîte à la noix, qui est réputé le meilleur morceau pour le bouillon ; du collier ou col avec l'os ; du paleron, c'est-à-dire de l'épaule ; du cimier, qui est le morceau pris sur la croupe ; de la côte ; enfin du flanchet : ce sont les portions cartilagineuses qui sont à la partie antérieure de la poitrine, à l'extrémité des côtes.*

*of broth could be made. When the whole was cooled down, the fat was removed and weighted; then the specific gravity of each broth was determined. Finally the broths were evaporated in order to recover the gelatinous part, and this part was reduced to the consistency of meat tablets.*<sup>15</sup>

This part is more like the modern "Materials and methods" section. It is a very important part because it gives to reviewers a possibility to ascertain the results, but also because it shows to readers how the results were acquired. As said before, many modern scientific journals properly impose to put this section before giving the results, as it is only when one knows how results were produced that one can accept to appreciate them. More generally, it is a good practice to structure scientific articles as Table 4.

Table 4.

1. Title
2. Authors
3. Abstract
4. Keywords
5. Introduction
6. Materials and methods
7. Results
8. Discussion
9. Conclusions and perspectives
10. Acknowledgements
11. Declaration of interests
12. References

15 *Toutes ces viandes étaient désossées, à l'exception du collier, auquel tenait l'os, la cuisson a duré sept à huit heures, avec une ébullition douce, et les dimensions ont été prises de manière à former juste deux livres de bouillon. Lorsque tout a été refroidi, on a séparé la graisse surnageant, qu'on a pesée ; on a ensuite déterminé la pesanteur spécifique de chaque bouillon. Enfin, on les a fait évaporer pour obtenir la partie gélatineuse, et cette dernière a été réduite à consistance de tablettes de bouillon.*

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Coming back to the article of L., let us observe that the description given could be improved by the information on the duration of the thermal processing. Here it is said that it was between 7 and 8 hours, but how much precisely? And why was this duration chosen? Was the meat put in cold water, or in hot water? How did the temperature change in function of time? What is "simmering"? How was the pan (dimensions, material)? Was there a lid? How much was the heating power?

L. wanted to make broth, but how did he do: did he take a known mass of meat, in order to add water and finally get 2 livres? For sure, the fat was weighted, but where is the information? How was the fat recovered? How much was lost during recovering? Was the fat dried? How was the broth evaporated? Why was it decided to stop the experiment at this particular consistency of "tablet" assuming these are well defined products? All these questions should have an answer in a modern publication.

*The table given in this memoir shows the results:*<sup>16</sup>

Here, L. publishes a table for which we give a translation in modern units, as today's publication would probably do.

Tables are one way to display scientific results, but one can observe that graphs would have made the presentation of results clearer. Moreover the dashed lines in the column giving the mass of fat seems to show that this mass was nil for thick flank, but a doubt remains and it could also be possible that the quantity was not measured. It would today be asked to write "0" or "n.d." (non determined), indicating also the signification of the acronym being used (in the caption).

Let us rather make the Table 5 (top of next page). This table is not homogeneous, as it contains the report of experiments of two

<sup>16</sup> *La table jointe à ce mémoire présente les résultats qu'on a obtenus ;*

different natures: modification of extraction depending on the proportion of water and meat, for thick flank only, and results for different kinds of pieces of meat.

For the first result, it would not be accepted today to give twice the same result; a good scientific practice is to synthesize as much as possible (in the same order of ideas, results should be published only once).

By the way, one could ask if L. repeated his experiments, determining a standard deviation. If we only keep the results on the comparison of the different muscular tissues, L. gives a proportion meat/water equal to 0.5000000. It is very surprising that, for such an experiment, a proportion with as many digits as wanted was really used. If it were the case, by an extraordinary luck, the reviewers and readers should be told.

*it will be seen that the differences in density change by one half, depending on the kind of meat being used, albeit coming from the same animal;*<sup>17</sup>

The expression "change by one half" is ambiguous. It can be seen on the histogram of Figure 9 that the different densities are very close.

Hence, in order to show more clearly the differences in densities of parts, it would have been better to display the differences, compared to the first data, for example (Figure 10).

*that the quantity of gelatinous part contained in the broth changes about in the same proportion ;*<sup>18</sup>

<sup>17</sup> *on y verra que les différences de pesanteur spécifique varient de plus de moitié, suivant l'espèce de viande employée, quoique toutes du même animal ;*

<sup>18</sup> *que la quantité de matière gélatineuse contenue dans le bouillon varie à peu près dans la même proportion*

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Quality of meat used	Quantity of meat used (en g)	Quantity of broth produced (en g)	Density (compared to water at a temperature of 20 °C ??)	Quantity of fat floating at the surface of the broth (en g)	Quantity of dried gel after evaporation (to be explained) (en g)
thick flank	1 <i>livre</i> + 4 <i>once</i> = 611.8750000	489.5	1.002322	?	36.5 <i>grain</i> = 1.938666450
thick flank	8 <i>once</i> = 244.7500000	489.5	1.003080	?	47.5 <i>grain</i> = 2.522922092
thick flank	1 <i>livre</i> = 489.5	489.5	1.007347	?	1 <i>gros</i> + 44 <i>grain</i> = 6.161241320
leg		489.5	1.005003	1 <i>gros</i> + 30 <i>grain</i> = 5.417643229	1 <i>gros</i> + 7 <i>grain</i> = 4.196017795
butt		489.5	1.004824	4 <i>gros</i> + 30 <i>grain</i> = 16.89029948	1 <i>gros</i> + 3 <i>grain</i> = 3.983561198
brisket		489.5	1.004391	4 <i>gros</i> + 55 <i>grain</i> = 18.21815321	68.25 <i>grain</i> = 3.625040690
cheek		489.5	1.004320	5 <i>gros</i> + 10 <i>grain</i> = 19.65223524	67 <i>grain</i> = 3.558648004
outside flank		489.5	1.003872	3 <i>gros</i> + 36 <i>grain</i> = 13.38476562	60 <i>grain</i> = 3.186848959
neck		489.5	1.003654	4 <i>gros</i> + 20 <i>grain</i> = 16.35915799	56.5 <i>grain</i> = 3.000949436
part of blade		489.5	1.003633	5 <i>gros</i> = 19.12109375	56 <i>grain</i> = 2.974392361
round		489.5	1.003304	2 <i>gros</i> + 2 <i>grain</i> = 7.754665799	51 <i>grain</i> = 2.708821615
rib		489.5	1.002937	3 <i>gros</i> + 53 <i>grain</i> = 14.28770616	45.25 <i>grain</i> = 2.403415256
hind quarter flank		489.5	1.002229	1 <i>once</i> + 3 <i>gros</i> + 55 <i>grain</i> = 44.98768446	34 <i>grain</i> = 1.805881077

Table 5

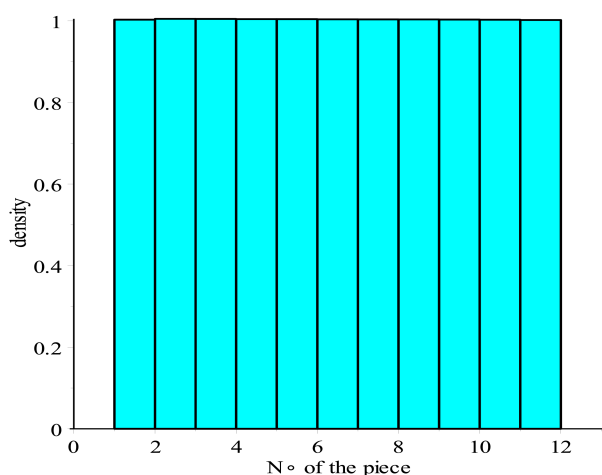


Figure 9. Histogram of densities (ordinates) depending on the particular piece of meat (the 11 pieces are given in Table 6).

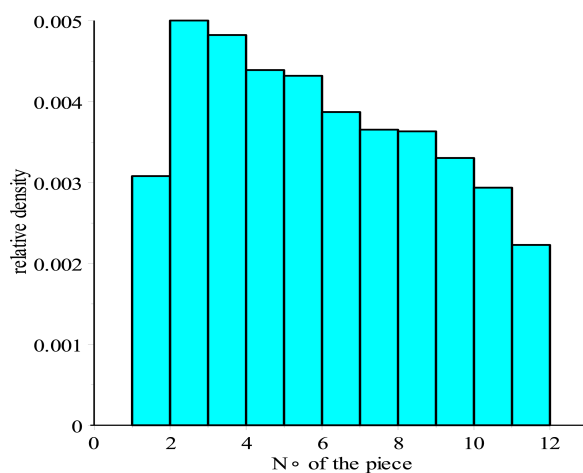


Figure 10. An improved representation for density (ordinate) for the various pieces (see Table 6).



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Quality of meat	density (compared to water at 20 °C ??)	Quantity of fat floating (en g)	Quantity of dried gel, after evaporation (en g)
thick flank	$d_1 := 1.003080$	?	$Qg_1 := 2.522922092$
thick flank	$d_2 := 1.005003$	$QGS_2 := 5.417643229$	$Qg_2 := 4.196017795$
leg	$d_3 := 1.004824$	$QGS_3 := 16.89029948$	$Qg_3 := 3.983561198$
brisket	$d_4 := 1.004391$	$QGS_4 := 18.21815321$	$Qg_4 := 3.625040690$
cheek	$d_5 := 1.004320$	$QGS_5 := 19.65223524$	$Qg_5 := 3.558648004$
outside flank	$d_6 := 1.003872$	$QGS_6 := 13.38476562$	$Qg_6 := 3.186848959$
neck	$d_7 := 1.003654$	$QGS_7 := 16.35915799$	$Qg_7 := 3.000949436$
part of blade	$d_8 := 1.003633$	$QGS_8 := 19.12109375$	$Qg_8 := 2.974392361$
round	$d_9 := 1.003304$	$QGS_9 := 7.754665799$	$Qg_9 := 2.708821615$
rib	$d_{10} := 1.002937$	$QGS_{10} := 14.28770616$	$Qg_{10} := 2.403415256$
hind quarter flank	$d_{11} := 1.002229$	$QGS_{11} := 44.98768446$	$Qg_{11} := 1.805881077$

Table 6. The pieces are numbered from top to bottom.

The "quantity of gelatinous part" is what we called Qg. Let us display the values (Figure 11).

Another representation of the same data is given in Figure 12.

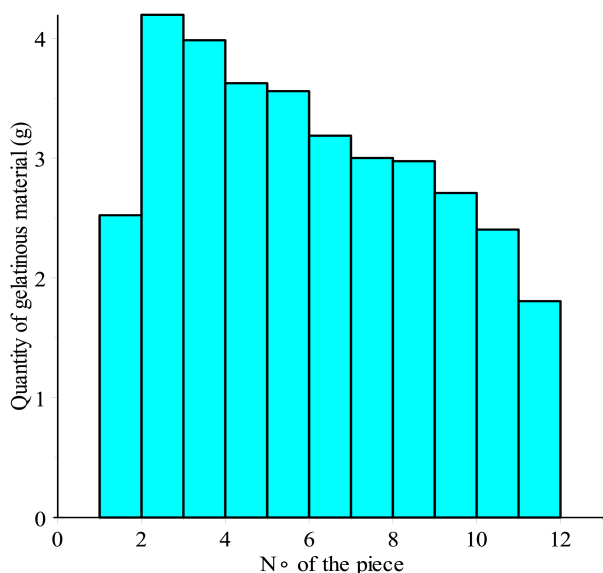


Figure 11. Mass of gelatinous material in function of the pieces (for the numbering of pieces, see Table 6).

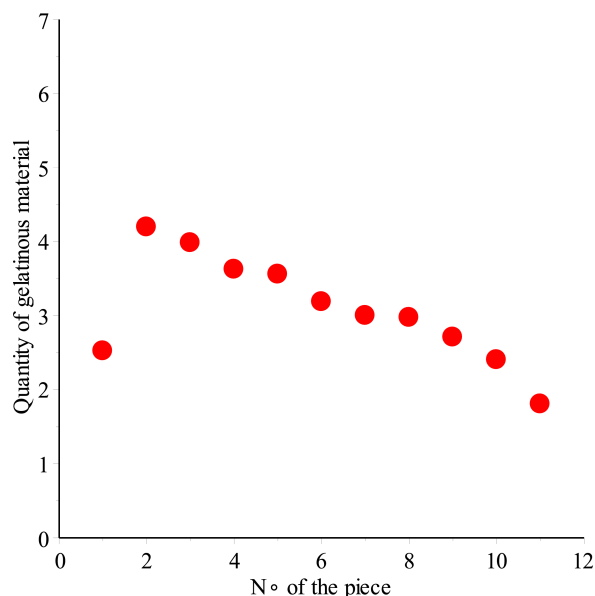


Figure 12. A different representation of data. Here again, the uncertainties are missing. For the numbering of pieces, see Table 6.

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The quantity of “gelatinous matter” would change in the same proportion that density? It is a good practice to display such a trend, because pictures give a clear idea, synthesizing the results at the same time (Figure 13).

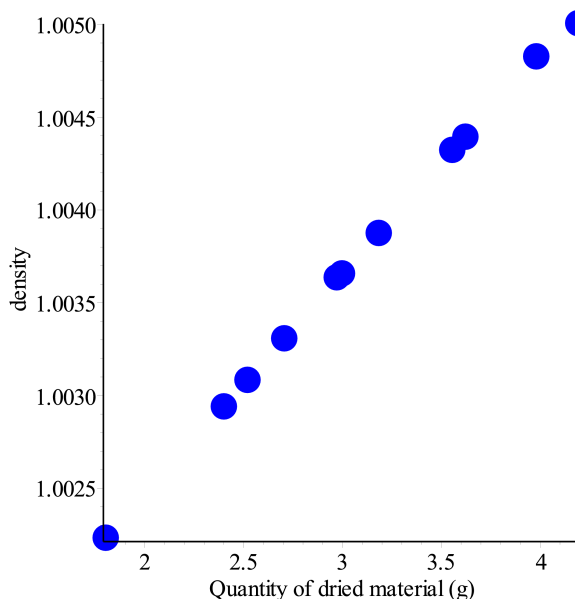


Figure 13. A linearity appears better on this diagram.

Now the Figure 13 shows clearly that it is right to say that the density is following a “relationship” (almost linear, the “almost” being to be quantified) in function to the quantity of dried matter. However, if this graphical presentation of results is fine, the quantification is better. Today many students use softwares for this purpose, and they display a regression line, with a  $R^2$  coefficient (Harris, 2010). This is not wrong, if one knows what one is doing, and how the  $R^2$  coefficient is calculated.

Let us begin by drawing a regression line:  
 $1.00011858299045 + 0.00117594067357360 x$   
 Then let us calculate the Bravais-Pearson correlation coefficient (Nogge, 1993):  
 0.9997249859.

*but in general a broth made from two parts of water for one part of meat should have a specific weight of 1003800, without taking into account the increase due to the addition of salt and vegetables; it should contain 1 gros 1/2 per livre of gelatinous matter when reduced as a tablet.<sup>19</sup>*

It is surprising that L. now writes something less precise than before.

*Because the large number of experiments that I did on the specific weight of broth, and on the quantity of gelatinous matter that they contain showed me the ratio of one with another, it was not difficult to recognize that the law followed was quite regular, and I succeeded to calculate it.<sup>20</sup>*

Again, there is a repetition. And in particular, what does “calculus” mean, when there is none, except a long table which is full of extrapolations (probably)?

*I did some particular experiments with broths from more meat than in the previous experiments, and I realized with more precision than I thought before, a table in which the quantity of gelatinous mater is in relationship with the specific weight.<sup>21</sup>*

<sup>19</sup> *mais qu'en général un bouillon résultant de deux parties d'eau contre une de viande doit avoir une pesanteur spécifique de 1003800, sans compter l'augmentation résultant de l'addition du sel et des légumes, et qu'il doit contenir un gros 1/2 à 2 gros par livre de matière gélatineuse à consistance de tablettes de bouillon.*

<sup>20</sup> *Le grand nombre d'expériences que j'avais faites sur la pesanteur spécifique des bouillons, et sur la quantité de matière gélatineuse qu'ils contenaient, m'ayant mis à portée de comparer le rapport de l'une avec l'autre, il ne m'a pas été difficile de reconnaître qu'il suivait une loi assez régulière, et je suis parvenu à la soumettre au calcul.*

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Here the text is ambiguous. Does L. want to say that he did only some experiments and that he extrapolated? If so, it would not be surprising that he could find a "very" linear relationship.

*In order to use this table more easily, I calculated by 6 grains. If one wanted to have more precision, and get the precision of 1 grain of gelatinous matter, one could use proportional parts, and on such small quantities there would be no sensitive error. Those who would like to go deeper in this direction will observe that the first differences of specific weight decrease as the broth is stronger, that the second differences decrease also, but that after 6 gros of gelatinous matter per livre of water, they reach a constancy.<sup>22</sup>*

It is obvious that if the interpolation is made from smaller intervals, variations will be smaller. Here modern best practices would have improved this part, including a discussion of

21 *J'ai fait d'ailleurs quelques expériences particulières sur des bouillons plus chargés que les précédents, et je me suis vu en état de former, avec beaucoup plus d'exactitude que je ne m'y étais attendu d'abord, une table qui exprime la quantité de matière gélatineuse contenue dans un bouillon d'une pesanteur spécifique donnée.*

22 *Pour faciliter l'usage de cette table je l'ai calculée de 6 en 6 grains. Si l'on voulait pousser plus loin l'exactitude et avoir, par exemple, jusqu'à la précision du grain la quantité de matière gélatineuse, on pourrait prendre des parties proportionnelles, et, sur d'aussi petites quantités, il n'en résulterait aucune erreur sensible. Ceux qui voudront approfondir les lois que suit cette table s'apercevront que les différences premières de la pesanteur spécifique vont en diminuant à mesure que le bouillon est plus chargé, que les différences secondes deviennent également plus petites à mesure que le bouillon se charge, mais que, vers 6 gros de matière gélatineuse par livre d'eau, elles arrivent à l'uniformité avec cette table.*

uncertainties or significant numbers. However it can be admired that even at his times L. gives a good method (Piskounov, 1980) for the exploration of experimental results on discrete data: when a derivative cannot be calculated, a finite difference can be determined.

*A scrupulous physician who would like to know how much nutritive matter he gives could do it easily; he just needs to determine the specific weight of broth, water being supposed to have a value of 1000000; when this specific weight is, for example 1009426, he will find in the table that 1 livre of this broth contains 4 gros 6 grains of gelatinous matter after reduction to the consistency of tablets.<sup>23</sup>*

### Why the scientific work was remarkable

Up to here, we almost forgot to admire the scientific work reported. It was not said here that after L. scientific and technological studies (in particular in nutrition science) went considerably backwards, perhaps because this particular memoir was forgotten (L. was guillotined in 1794). Scientists such as François Magendie (1783-1855) tried to demonstrate that gelatin has no nutritional properties, as dog fed with meat tablets died after weeks of exclusive diet. And it was forgotten that density is indeed an excellent

23 *Un médecin scrupuleux, qui voudra connaître ce qu'il donne de matière nourrissante à son malade, le pourra facilement ; il ne s'agira que de déterminer la pesanteur spécifique du bouillon, l'eau étant supposée 1000000 ; si cette pesanteur spécifique se trouve, par exemple, être de 1009426, il trouvera dans la table que 1 livre de ce bouillon contient 4 gros 6 grains de matière gélatineuse, à consistance de tablettes sèches. On observe qu'il est toujours question ici de bouillon non salé.*

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indicator of the quantity of dissolved matters, in particular gelatin (Cadet de Vaux, 1818; Darcet, 1830; Liebig, 1852; This, 2008).

Also the method devised by L. is remarkable, in order to get an idea of the quality of broth.

*The usefulness of the table depends on the particular ways for the precise determination of specific weight. Indeed the differences, from one broth to another, being very small, one would commit large errors if the instruments were not precise for measuring small differences; as a consequence, I shall explain which tools I am using.<sup>24</sup>*

Now, L. discusses the issue of precision, and this shows that the modern practices of putting the "Materials and Methods" section before the results is a good one. This would have allowed the calculation of experimental uncertainties, and an improved display of results.

*The hydrometer that I use is a hollow cylinder made of a thin silver sheet, strong enough to avoid bending when the instrument is cleaned. This cylinder is weighted at the bottom with tin, and it has a stem on top, made from a silver thread of 3/4 line of diameter, to which is adapted a small cup in which weights can be put; I made a mark on the stem at the place where the level of the liquid should be.<sup>25</sup>*

24 L'utilité qu'on peut retirer de la table ci-dessus suppose qu'on a des moyens très-exacts pour déterminer la pesanteur spécifique. En effet, les différences d'un bouillon à l'autre étant très-petites, on commettrait de grosses erreurs si l'on n'avait des instruments assez délicat pour saisir de très petites différences ; je vais, en conséquence, exposer ceux que j'emploie.

25 Le pèse-liqueur dont je me sers est un cylindre creux formé d'une feuille d'argent mince, assez forte cependant pour ne pas plier et se déformer quand on essuie l'instrument. Ce cylindre est lesté par le bas avec de l'étain fin, et il est surmonté, à son extrémité supérieure, par une tige de fil d'argent de

This description is now a good indicator of the precision of the studies performed by L.: technical details are given, and some methodological cleverness is obvious. This hydrometer, as the Fortin balance, became later important in chemistry (Crosland, 1978).

*When this tool is made and when weights are added to the cylinder so that the whole instrument is slightly lighter than the volume of water it displaces, it is weighted on a very precise balance, then it is dipped in distilled water, and a certain number of grains and fractions of grains are added on the top cup so that the hydrometer goes down until the level of the liquid reaches the mark on the stem; the same process is performed with the liquor for which specific weight is to be determined , and from the masses the specific weight can be determined in millionth.<sup>26</sup>*

Here the text is perfectly clear. Moreover this part of the text shows that L. used the "method of zero" before Louis-Marie Ampère, to which the method is attributed by James Clark Maxwell (Traçon, 1997). What is this method? Let us explain it using an example from electricity: when the variations of the

*3/4 de ligne environ de diamètre, à laquelle est adapté un petit godet destiné à recevoir des poids ; j'ai fait une marque sur la tige à l'endroit jusque auquel le pèse-liqueur doit être enfoncé.*

26 Lorsque cet instrument est construit et qu'il est lesté de manière à être un peu plus léger que le volume d'eau qu'il déplace, on le pèse à une balance très-exacte, on le plonge dans de l'eau distillée, puis on ajoute, sur le petit bassin supérieur, le nombre de grains et de fractions de grain nécessaire pour le faire enfoncer jusqu'à la marque pratiquée sur la tige ; on fait la même opération avec la liqueur dont on veut déterminer la pesanteur spécifique, et par le rapport du poids total, tant du pèse-liqueur que des grains qui y ont été ajoutés, on conclut la pesanteur spécifique en millionièmes.



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intensity of a electric current of average intensity 1000 A are to be determined precisely, a good way is to avoid measuring directly the intensity, because if fluctuations are for example 1 A, then the quantity to be determined would be too small; however if a signal of constant intensity -1000 A is added to the first, the sum of the two signals is at the maximum of 1 A, so that the variation is 100 %. Here it is what L. is doing: instead of directly reading the density on a graduated stem, he puts the system at constant level, and improves the precision, as we shall calculate below.

How did L. do? Let us observe that he used a hydrometer for which the stem is very thin: this is important, because the following calculation shows that the variations of depth are increased.

Let us first observe that the hydrometer is in equilibrium in distilled water because it is submitted to forces whose resultant is nil. These forces are the weight and the buoyancy force, i.e. the resultant of pressure forces.

The weight  $P$  is proportional to the mass  $M$ :

$$P = m \cdot g \quad (1)$$

The proportionality constant  $g$  is the acceleration of gravity.

On the other hand, the buoyancy force is equal to the weight of water displaced by the immersed volume of the hydrometer. If this tool is made from a cylinder of volume  $v$  (entirely in water) with a cylindrical stem of radius  $r$ , the stem is at a height  $h_w$ . The volume of the hydrometer inside water is:

$$V = v + \pi \cdot r^2 \cdot h_w \quad (2)$$

The displaced volume of water is linked to the mass of displaced water  $M_w$  by the definition of specific weight (for water):

$$\rho_w = \frac{M_w}{V} \quad (3)$$

Finally the equilibrium condition in pure water is:

$$Mg = (v + \pi \cdot r^2 \cdot h_w) \cdot \rho_w \cdot g \quad (4)$$

If the specific weight changes by  $\Delta\rho$ , from  $\rho_w$

to  $\rho_w + \Delta\rho$ , the question is: how much does the hydrometer sink? The equilibrium equations can be written for the two conditions (water and broth):

$$Mg = (v + \pi \cdot r^2 \cdot (h_w + \Delta h)) \cdot (\rho_w + \Delta\rho) \cdot g \quad (5)$$

By subtraction:

$$(v + \pi \cdot r^2 \cdot h_w) \cdot \rho_w \cdot g = (v + \pi \cdot r^2 \cdot (h_w + \Delta h)) \cdot (\rho_w + \Delta\rho) \cdot g \quad (6)$$

(6)

Let us suppress the same terms from both sides; we find:

$$\Delta h = \frac{v \cdot \Delta\rho + \pi \cdot r^2 \cdot h_w \cdot \Delta\rho}{-\rho_w \pi \cdot r^2 - \pi \cdot r^2 \Delta\rho} \quad (7)$$

This function is of the kind

$$y = \frac{-(1+r^2)}{-r^2} \quad (8)$$

For small values of  $r$ , the variation  $y(r)$  is very large (in  $1/r^2$  ; it is negative because the hydrometer goes up when the density increases, as in a broth). This observation shows how the work by L. is smart.

How useful is the method of zero for stock density determination? We shall now calculate the uncertainty of the direct method, and the method of zero.

In order to calculate the uncertainty on density as determined by the direct method, let us begin by writing the equilibrium equation in pure water: the hydrometer is in equilibrium when its weight is equal to the Archimedes lift, a force equal to the the weight of the volume of displaced water.

Here we assume that the mass of the hydrometer is  $M$ , with a cylinder of volume  $v$  and a cylindrical stem of radius  $r$ . The stem is in water by the height  $h_w$  and again the specific weight of water is  $\rho_w$ .

Using these variables, the equilibrium equation is:

$$Mg = (v + \pi \cdot r^2 \cdot h_w) \cdot \rho_w \cdot g \quad (9)$$

In broth, the equation is the same, but the specific weight of pure water is replaced by the broth specific weight  $\rho_b$ :

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$$Mg = (v + \pi \cdot r^2 \cdot h_b) \cdot \rho_b \cdot g \quad (10)$$

How much is the density of the broth? Let us observe that it is equal to the ratio of the volumic mass by the one of pure water:

$$d = \frac{\rho_b}{\rho_w} \quad (11)$$

The volumic mass of broth appears in equation 9, and the one for water in equation 10. So that:

$$d = \frac{\frac{M}{v + \pi r^2 h_b}}{\frac{M}{v + \pi r^2 h_w}} \quad (12)$$

Here the volume appears. This one is difficult to measure precisely, but is linked to mass, the latter being known with much better precision, so that:

$$d = \frac{\left(\frac{M}{\rho_w} - \pi r^2 h_e\right) + \pi r^2 h_e}{\left(\frac{M}{\rho_w} - \pi r^2 h_e\right) + \pi r^2 h_b} \quad (13)$$

Or :

$$d = \frac{M}{M - \pi r^2 h_w \rho_w + \pi r^2 h_b \rho_b} \quad (14)$$

It can be observed that the density depends on  $M$ , the specific weight of water, the radius, the sinking depth in water, the sinking depth in the broth. Finally the uncertainty on density can be calculated. It is equal to 0.00529, with the values given by L.

On the other hand, in order to determine the uncertainty using the method of zero, one has again to express the equilibrium condition in pure water:

$$M_w g = (v + \pi \cdot r^2 \cdot h_w) \cdot \rho_w \cdot g \quad (15)$$

Then in the broth, the depth does not change, but the mass is changing, because small masses are added in the upper part:

$$M_b g = (v + \pi \cdot r^2 \cdot h_w) \cdot \rho_b \cdot g \quad (16)$$

One has again to make a ratio, so that:

$$d = \frac{\frac{M_b}{v + \pi r^2 h}}{\frac{M_w}{v + \pi r^2 h}} \quad (17)$$

One can immediately observe that the causes for uncertainties are reduced. And the uncertainties are on masses, known with much more precision than distances (in particular in presence of a meniscus). Numerically it can be calculated that the uncertainty is equal to 0.0002, i.e about 20 times smaller than before. Obviously the work of L. is remarkable, even if his article is not done according to modern criteria.

#### Was Lavoisier's method precise enough to distinguish broth from density?

Finally could really L. distinguish the quantity of extracted matter with a small proportion of water and with a large quantity of water? The reproduction of L. experiments showed that the answer is yes: the Figure 14 shows the quantity of dried matter of a broth in a function of the duration of thermal processing, for two meat/water proportions. In our experiments, we replaced the silver stem by a small capillary tube (Hirschmann Laborgeräte 5  $\mu$ L, length 7.642 cm, external diameter 1.3 mm,  $R \leq 0.3$  %) that was glued at the top of a fishing float; at the bottom of the float, weights were adapted so that the system was partially in the liquid whose density was measured. As for L. experiments, a small cup was adapted at the top of the stem, and small masses were added, in order to keep always the same sinking depth.

This system was calibrated by using ultrapure water and a solution obtained by dissolution of known quantities of gelatin (previously dried in an oven at 95 °C until three constant measurement, then stored for two days in a desiccator with phosphorus pentoxide  $P_2O_5$ ). Our experiments were performed at the

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temperature of 18°C ( $\pm 0.1$  °C), in order to avoid variations of density with temperature. In the Figure 14, measurements uncertainties are smaller than the size of experimental data points: one can now see very clearly that a large quantity of water (red dots) is extracting more than a small quantity of water.

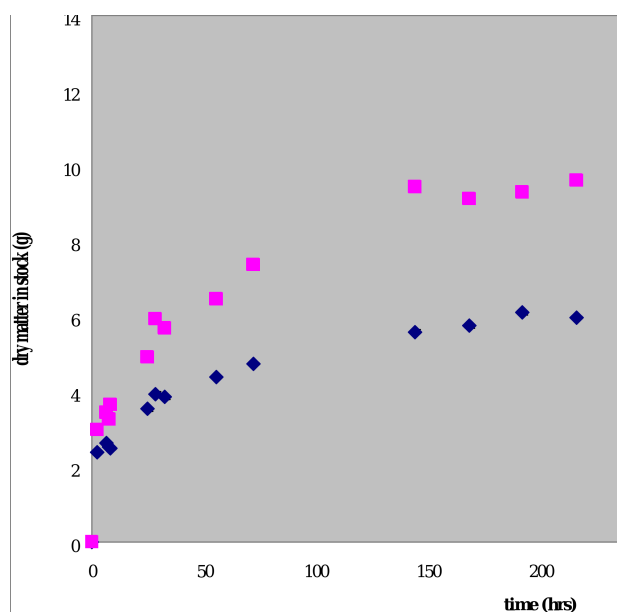


Figure 14. Dried matter of broth in function of time of thermal processing for two different proportions of meat and water.

*The hydrometer that I am using is displacing slightly more than 9 onces of distilled water.*<sup>27</sup>

Here one should ask why L. is providing information that seems useless. In a modern publication, as said before, anything useless should be dropped (this will perhaps change with free open journals, on line, where there is more space than on printed documents). On the other hand, one can see the methodological advance: if the rule is to avoid useless information, it invites the readers to consider

<sup>27</sup> Le pèse-liqueur que j'emploie déplace un peu plus de 9 onces d'eau distillée.

that any given information is useful. Here, L. would have been invited by the reviewers to explain why he gave this information.

*I gave detailed information on the hydrometer because it can be useful in a large number of processes in pharmacy, and, whereas I am using it for many experiments, I did not describe it before.*<sup>28</sup>

It is strange that L. used this hydrometer in previous works and that he did not describe it before: today, he would have had to explain the system on the first time he was publishing a result obtained with it. Then, in following articles, he would have had to give the reference of the article where he gave the description.

*Because the work presented here was motivated by discussions on the quantity of broth that one should give in hospitals, it is natural to examine now the application of these results for humankind.*<sup>29</sup>

This statement is important, because the work was done for technological reason: if such a work is useless, it is paradoxical.

*The king is giving, in hospitals of the Navy, one livre of meat per person, whatever the degree of sickness or of recovery. One can ask: 1° is this quantity enough? ; 2° whether*

<sup>28</sup> Je suis entré dans quelques détails sur cet instrument, parce qu'il peut être d'un usage commode dans un grand nombre d'opérations de pharmacie, et que, d'ailleurs, quoi que je m'en serve habituellement, je n'en ai donné la description dans aucun autre mémoire.

<sup>29</sup> Les conférences sur la quantité de bouillon qu'on doit donner dans les hôpitaux ayant été l'occasion du travail dont je viens de rendre compte, il est naturel d'examiner maintenant les applications qu'on peut en faire à un objet aussi intéressant pour l'humanité.

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*it is necessary or possible to increase it, how can we get the best from it?  
One will find easily the answer to these two questions in the experiments discussed here.*<sup>30</sup>

All this is clear... but why is it in a conclusion, and not as an introduction? This can be discussed.

*Table of quantities of solid jelly reduced to the consistency of meat tablets*<sup>31</sup>

This table is at the end of the article, as an annexe. Modern scientific publications follow this rules. In recent years, such information was given sometimes in "supplemental materials", but the online publication will allow readers to find it as it was in the past.

Let us conclude now: with this work, L. obtained more information than many scientists before or after him. Historians discussed the importance of L. for the design of precise balances, but the precision of his hydrometer was less analyzed. Even if we amply discussed the publication given here, it remains that, with early methodology, L. got results of remarkable quality.

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<sup>30</sup> *Le roi accorde, dans les hôpitaux de la marine, une livre de viande un malade, l'un portant l'autre, quel que soit le degré de convalescence ou de maladie. On peut demander, 1° si cette quantité est suffisante ; 2° dans la supposition où il ne serait pas nécessaire ni même possible de l'augmenter, quel est le meilleur parti qu'on peut tirer de cette quantité ? On trouvera facilement dans les expériences ci-dessus la réponse à ces deux questions.*

<sup>31</sup> *Table des quantités de gelée solide réduite à consistance de tablettes*

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