1 Introduction

The primary aim, in teaching physics, is that the student should gain an understanding of the principles of physics and how to apply them to different problems. A secondary aim is to allow the students to appreciate the scientific approach and significance of it in the evolution of science and society. One approach for the second aim has been to include "historical material" in physics textbooks. The quantity of the historical material included is quite diverse, from textbooks with a very strong historical approach to others without any historical material. The quality of the material included is also diverse. In this article we focus on the development of the historical material, i.e. a certain historical development, in a specific textbook (Sears & Zemansky’s University Physics) over a number of editions. The aim is to see when and how the historical material is included and how well it describes the actual history. Will the physics adapt to history or vice-verse.

The event of interest is the introduction of the Blackbody radiation formula or Planck’s radiation formula. This is well known out of an historical perspective, but also a case where a quasi-historical is quite common in textbooks.

2 Planck’s radiation formula

There exist excellent accounts of the development of quantum theory in general [1][2][3] as well as detailed studies of Planck’s radiation formula [4][5][6], why we will not go into detail on the history, but try to give a general outline.

The development of spectroscopy made it possible to study spectra from different elements but also from macroscopic objects. In 1859 argued Robert Kirchhoff that black-body radiation was of a fundamental nature, thus initiating an interest in these studies. The spectral distribution were investigated by several physicists, both experimentalists and theorists. In 1896 Wilhelm Wien found a radiation law that was in agreement with precise measurements performed at the Physikalisch-Technische Reichsanstalt in Berlin.
According to Wien the spectral density is described as:

\[ u(f, T) = \alpha f^3 e^{-\beta f/T} \]

where \( \alpha \) and \( \beta \) are constants to be determined empirically, \( f \) and \( T \) are frequency and temperature, respectively. However, this lacked a theoretical foundation, something that Max Planck could not accept. Planck formulated a "principle of elementary disorder", which he used to define the entropy of an ideal oscillator. Using this it was possible for Planck, early in 1899, to find an expression from which Wien’s law followed.

However, measurements by Lummer and Pringsheim in November 1899, showed a deviation from Wien’s law at low frequencies. Planck had to revise his calculations, using a new expression for the entropy of a single oscillator. The new distribution law was presented at a meeting of the German Physical Society on 19 October 1900. The spectral density was now given as:

\[ u(f, T) = \frac{\alpha f^3}{e^{\frac{hf}{kT}} - 1} \]

where \( \alpha \) and \( \beta \) are constants to be determined empirically, \( f \) and \( T \) are frequency and temperature, respectively. The problem was, as Planck realized, that his new expression was no more than an inspired guess. Planck had not used energy quantization nor Boltzmann’s probabilistic interpretation of entropy.

In what he himself describes as "an act of desperation", he turned to Boltzmann’s probabilistic notion of entropy. Even if he adopted Boltzmann’s view, he did not convert to the probabilistic notion of entropy. He remained convinced that the law of entropy was absolute, not probabilistic, and therefore reinterpreted Boltzmann’s theory in his own non-probabilistic way. Using the "Boltzmann equation"

\[ S = k \log W \]

, which relates the entropy, \( S \), to the molecular disorder, \( W \). In order to determine \( W \), Planck had to be able to count the number of ways a given amount of energy can be distributed in a set of oscillators. It was in doing this Planck introduced what he called "energy elements", that is the total energy of the black-body oscillators, \( E \), divided into finite portions of energy, \( \varepsilon \), via a process known as "quantization". The energy of the finite energy elements were given by a constant, \( h \), multiplied with a frequency \( f \).

\[ \varepsilon = hf \]

Using this it was easy for Planck to follow the procedure that Boltzmann used in deriving Maxwell’s distribution of velocities of molecules in a gas and derive the spectral density:

\[ u(f, T) = \frac{8 \pi}{c^3} \frac{hf^3}{(e^{\frac{hf}{kT}} - 1)} \]
This was presented to the German Physical Society on 14 December 1900 [7], followed by four papers in 1901.

Lord Rayleigh published a paper in June 1900 [8] where he presented an improved version of Wien’s radiation law. Using Maxwell-Boltzmann’s equipartition theorem, he obtained a different radiation law:

\[ u(\lambda, T) = c_1 \frac{T}{\lambda^4} e^{-\frac{c_2}{\lambda T}} \]

This law was noted and tested by experimentalists, but got very little attention since Planck had produced a formula that was a better fit to the experimental results. In 1905 came Rayleigh [9] with a refined radiation law:

\[ u(\lambda, T) = \frac{64\pi kT}{\lambda^4} \]

An error in the calculations was corrected by Jeans [10] and the new radiation law was therefore named Rayleigh-Jeans law:

\[ u(\lambda, T) = \frac{8\pi kT}{\lambda^4} \]

The result is an energy density that increases as the frequency gets higher, becoming "catastrophic" in the ultraviolet region. This made Paul Ehrenfest coin the name "ultraviolet catastrophe" in 1911, thus becoming a matter of discussion quite late in the development of quantum theory.

Einstein was the first to fully adopt the quantisation principle in his derivation of Planck’s radiation law in 1906 [12]. Something that caused an increased interest among physicists, leading to more discussions.

The time scale is quite clear: Planck’s Radiation law origins from 1900, Rayleigh-Jeans law from 1905 and the term "ultraviolet catastrophe" from 1911.

From a physical point of view, the order of the radiation laws will be different. Based on classical physics, i.e. no quantization, Rayleigh-Jeans law should be placed before Planck’s law. Also the use of the Maxwell-Boltzmann’s equipartition theorem, makes it natural to derive it after the Maxwell–Boltzmann distribution.

3 Sears & Zemansky’s University Physics

The textbook chosen for this study, is Sears & Zemansky’s University Physics with the first edition published in 1949 [13] and with later editions widely used around the world. At many universities this textbook is the first (and sometimes the only) choice, leaving a rather large impact on students. Since this textbook has a long history will it be the obvious choice when studying the developments of textbooks. Since the first edition in 1949 [13], a number of editions has been published. The responsible authors have changed over the years. The first four editions, 1949 [13], 1955 [14], 1963 [15] and 1970 [16] were written by Sears and Zemansky. The fifth edition, from 1976 [17], was coauthored by Young. This
edition was also the last coauthored with Sears who died suddenly during the final preparing stages of the manuscript. Six years later, in 1982 [18], the sixth edition was published, this being the last with Zemansky who died in 1981 after the new manuscript had been finished. The seventh and eight editions were authored by Young, 1987 [19] and 1992 [20], respectively. The ninth edition included Freedman as co-author, something that has been the case for the last editions up to date, ninth edition in 1996 [21], tenth to thirteenth, 2000 [22], 2004 [23], 2008 [24], and 2012 [25], respectively.

It should also be mentioned that a number of contributing authors has been used over the years, further informations on these can be found in the preface of the different editions.

Having a textbook that has evolved from the start over 60 years ago, gives an unique opportunity to probe the development of the teaching of physics. Both in the presentation and the layout, but also in the examples and derivations used. In this case we are more interested in the development of how a specific historical development is presented and how it is changing. One have to remember that University Physics was not written in a vacuum, there existed other textbooks before, and Sears had written a book before. The first edition followed the a basic outline, with a conventional selection and sequence. Mechanics, heat, sound, electricity and magnetism, and optics. Modern Physics were added after the first editions, with atomic physics as the first modern subject to be included. It is clearly stated in the preface of the first editions (up to the seventh) that:

The emphasis is on physical principles; historical background and practical applications have been given a place of secondary importance. [15, Preface]

The eighth edition [20] is a comprehensive revision aimed at the changes in the background and needs of the students as well as a change in the philosophy of introductionary physics courses. One effect of this being an attempt to make physics more human, in part by including the history of physics. One should note that the third edition [15] is special, as it marks an increased difficulty in the presentation as well as introduction of new approaches. However, the fourth edition [16] is a step back to the earlier presentations and a slight reduction in the mathematical difficulty.

3.1 Blackbody radiation in University Physics.

In the first and second editions the Blackbody radiation is described from an experimental radiation view, without mentioning Planck’s quantisation. Blackbody radiation and Planck’s quantisation is mentioned in the third edition of University Physics, in the thermodynamics section (Chapter 17-7 Planck’s law [15]). The description differs from earlier editions, with a discussion on the origin of Planck’s law, as the earlier editions just described Blackbody radiation from a radiation point of view without mentioning Planck’s quantisation. The presentation in the third edition, does not emphasize on the history, but on a more experimentally observed approach:
Max Planck, in 1900, developed an empirical equation that satisfactory represented the observed energy distribution in the spectrum of a Blackbody. After unsuccessful attempts to justify his equation by theoretical reasoning based on the laws of classical physics, Planck concluded that these laws did not apply to energy transformations on an atomic scale. Instead, he postulated that a radiating body consisted of an enormous number of elementary oscillators, some vibrating at one frequency and some at another, with all frequencies from zero to infinity being represented.[15, p 380]

The discussion in the fourth, fifth and sixth editions, is very similar to the discussion in the first two editions, making the third edition special.

It is with the seventh edition (1987) that Planck makes his entrance in a chapter on continuous spectra (Chapter 41-7 [19]). The presentation takes a starting point in the empirical Stefan-Boltzmann Law and the Wien displacement law, and describes how Planck in 1900 used the principle of equipartition of energy together with a quantisation of the energy that is emitted or absorbed. The presentation does not emphasise the history but states:

Finally, in 1900 Max Planck succeeded in deriving a function, now called the Planck radiation law, that agreed with experimentally obtained power-distribution curves. To do this he added to the classical equipartition theorem the additional assumption that a harmonic oscillator with frequency f can gain or lose energy only in discrete steps of magnitude hf, where h is the same constant that now bears his name.

Ironically, Planck himself originally regarded this quantum hypothesis, as a calculational trick rather than a fundamental principle. But as we have seen, evidence for the quantum aspects of light accumulated, and by 1920 there was no longer any doubt about the validity of the concept. Indeed, the concept of discrete energy levels of microscopic systems really originated with Planck, not Bohr, and we have departed from the historical order of things by discussing atomic spectra before continuous spectra.[19, p995]

It is notable that there is no discussion on the development of physics, it is just the result that is important. The description differs from the historical development but can not be considered as quasi-history.

3.2 Changes in the eight edition.

The eight edition (1992)[20] show some major changes, the title now includes modern physics, and the material in this section has changed a lot and new material has been added. In the case of continuous spectra (Chapter 40-8) , the discussion about the physics behind has been modernised, but the history has also been extended with the derivation of Rayleigh-Jeans law from 1905, presented as a precursor to Planck’s Law from 1900!
During the last decade of the nineteenth century, many attempts were made to derive these empirical results from basic principles. In one attempt, Rayleigh considered light enclosed in a rectangular box with perfectly reflecting sides. Such a box has a series of possible normal modes for the light waves, analogous to normal modes for a string held at both ends (Section 20-3). It seemed reasonable to assume that the distribution of energy among the various modes was given by the equipartition principle (Section 16-4), which had been successfully used in the analysis of heat capacities. A small hole in the box would behave as an ideal Blackbody radiator. Including both the electric- and magnetic-field energies, Rayleigh assumed that the total energy of each normal mode was equal to kT. Then by computing the number of normal modes corresponding to a wavelength interval \( d\lambda \), Rayleigh could predict the distribution of wavelengths in the radiation within the box. Finally, he could compute the intensity distribution \( I(\lambda) \) of the radiation emerging from a small hole in the box. His result was quite simple:

\[
I(\lambda) = \frac{2\pi c k T}{\lambda^4} \tag{40-30}
\]

At large wavelengths this formula agrees quite well with the experimental results shown in Fig. 40-27, but there is serious disagreement at small \( \lambda \). The experimental curve falls to zero at small \( \lambda \); Rayleigh's curve approaches infinity as \( 1/\lambda^4 \), a result called in Rayleigh's time the "ultraviolet catastrophe." Even worse, the integral of Eq. (40-30) over all \( \lambda \) is infinite, indicating an infinitely large total radiated intensity. Clearly, something is wrong.

Finally, in 1900, Planck succeeded in deriving a function, now called the Planck radiation law, that agreed very well with experimental intensity distribution curves. To do this, he made what seemed at the time to be a crazy assumption; he assumed that in Rayleigh's box a normal mode with frequency \( f \) could gain or lose energy only indiscrrete steps with magnitude \( hf \), where \( h \) is the same constant that now bears Planck's name.[20, p1129-1130]

Note the sharp wording in connection to Planck's assumption. We also find a change in the description of development of physics, which is now a part of the discussion. This indicates a desire to discuss how the results were obtained. But we can also notice that the description of events does not follow the actual history, in which Rayleigh plays a minor part.

Planck was not comfortable with this quantum hypothesis; he regarded it as a calculational trick rather than a fundamental principle. In a letter to a friend he called it "an act of desperation" into which he was forced because "a theoretical explanation had to be found at any cost, whatever the price." But five years later, Einstein extended this concept to explain the photoelectric effect (Section 40-2), and other evidence quickly mounted. By 1915 there was no
longer any doubt about the validity of the quantum concept and the existence of photons. By discussing atomic spectra before discussing continuous spectra, we have departed from the historical order of things. The credit for inventing the concept of quantization goes to Planck, even though he didn’t believe it at first. [20, p1130]

Note that the year for acceptance of quantisation has changed from 1920 to 1915!

It is clear that the style of the book has changed in such a way that it is not sufficient to just present the results but the development on how the results was found is becoming more important.

The ninth (1996) [21], tenth (2000) [22] and eleventh (2004) [23] editions are almost the same as the eight, with minor changes in the presentation.

3.3 Changes in the twelfth edition.

In the twelfth edition (2008) [24] the change is not in the presentation but in the fact that Rayleigh’s derivation is now given as a separate subsection with a special heading, Rayleigh and the ”Ultraviolet Catastrophe”, in section 38.8. As before placed before Planck’s derivation which also is given a separate subsection with a special heading, Planck and the Quantum Hypothesis. With the presentation and now subsection the quasi-history is enhanced, leading further away form the actual events.

3.4 The thirteenth edition (2012)

The presentation in the thirteenth edition [25] is the same when it comes to history. But now an analogy is introduced to explain the difference between line spectra and continuous spectra. In Planck’s derivation, the discussion is extended and coupled more towards thermodynamics and Boltzmann distributions.

4 Discussion

It is clear that the presentation style changed from a result-centered approach to a broader approach as from the eighth edition, where the idea to make it more interesting but introducing a human dimension by telling the history. The aim is to present a logical presentation of the scientific facts, but also to provide a historical framework inside which the scientific facts fit easily. Thus creating a development of physics that make sense and is easily remembered. In this process, the historical events have to adapt to the physics, in such way that students could follow a ”logical” development. However, the history is seldom ”logical”, so that it is easy to rewrite history to fit the physics. In doing so one misses the chance to discuss the foundations of physics and why these might seem to be counterintuitive. It is important to show that understanding and finding the correct theory is seldom straightforward. If the students have
trouble to understand a theory it might be comforting to know that the persons
developing the theory also had problems in understanding it.

The textbook studied, does not follow the historical development, but tend
to enhance a quasi-historical myth, when placing a reasonable results-centered
presentation in a false historical context. The intentions and the pedagogical
motivation can be considered to be solid, but unfortunately this gives a false
picture of the history and nature of physics.

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