A New Interpretation of the Newton’s Cooling Law: Two Features of Thermons: Their Elastic Volume and Their Angular Momentum

Jiří Stávek

Abstract — The Newton’s cooling law still attracts the attention of scholars in order to describe hidden features of heat particles (thermons) and the mechanism of the radiating heat into the surroundings with a lower temperature. The characteristic cooling constant of this process $1/\tau_e$ [min$^{-1}$] was defined as the experimental parameter describing the contributions of the thermon elastic volume and thermon angular momentum. This experimental parameter $\tau_e$ was found as the time needed to achieve the temperature $T_i = T_{out} - (T_i - T_{in})/\pi$ during the cooling of the studied object with the starting temperature $T_i$ and the surrounding with temperature $T_{out}$. The studied system was water in spherical flasks with the volumes 2000, 1000, 500, 250, and 100 mL and the starting temperatures 90° C, 80° C, and 70° C. The temperature of the surrounding was 24° C (laboratory temperature) and (4° ± 2°) C (outdoor temperature on March 5, 2023 near Prague). There was one critical experimental parameter: where to place the thermometer in the spherical flask: 1. inside to the bottom wall, 2. in the center of spherical flask, 3. at the upper level of the water volume, 4. outside to the bottom wall. For all experimental runs we have found that the temperature $T_i$ measured at the inside bottom wall of the spherical flasks might be interpreted as the “true” Newtonian temperature while the characteristic cooling constant $\tau_e$ is very close to the value of the slope in the semi-log graph of those cooling systems. This model was used to interpret the historical experimental data of Newton (1701) and the modern experimental data of Grigull (1984). This model opens a new view on the Carnot engine where the elastic volume of thermons can achieve the efficiency $\eta_1 = (T_{HOT} - T_\ell)/(T_{HOT} - T_{COLD}) = 1/\pi \approx 0.682$. Moreover, the “waste heat” after the Carnot engine can be used in the Seebeck generator to convert the angular momentum of thermons into the electricity (thermoelectric generator) with the efficiency $\eta_2 = (T_\ell - T_{COLD})/(T_{HOT} - T_{COLD}) = 1/\pi \approx 0.318$. The combined Carnot (1824) – Seebeck (1825) engine can explore all available heat of the of thermons for the temperature difference $T_{HOT} - T_{COLD}$.

Keywords — Carnot Heat Engine, Measure of the Quantity of Heat S, Newton’s Cooling Law, Seebeck Generator, Thermon Angular Momentum, Thermon Elastic Volume, Thermon Transfer of Heat.

I. INTRODUCTION

Newton is credited with the discovery of the cooling law, that was published anonymously in 1701 as “Scala Graduum Caloris” (A Scale of the Degrees of Heat) [1]. During past three centuries many scholars collected valuable experimental data to this topic: some pioneer contributions [2]-[7], several important reviews [8]-[27], some advice how to measure the cooling constant [28]-[30].

It seems that during those three hundred years all possibilities how to interpret the Newton’s cooling law were published, and no new experimental data can bring any deeper insight into the mechanism of the Newton’s cooling law. During the last century there were many attempts to resurrect the old model of caloric [31]-[59] but these attempts could not pass through the barrier protecting the mechanical model of heat.

Recently, Stávek [60],[61] introduced thermons as possible carriers of heat and proposed several experimental tests for the evaluation of the reality of that model. Can we newly interpret measured temperatures during experiments based on the Newton’s cooling law?

II. THERMONS: THEIR ELASTIC VOLUME AND THEIR ANGULAR MOMENTUM

Some stimulating ideas we can rediscover in the historical literature from Old Masters who anticipated properties of carriers of heat (e.g., Comenius in his “Disquisitiones de Caloris et Frigoris Natura” in 1659 interpreted carriers of heat and cold as “caloris” and “frigoris” and explained them as the torsion of matter...
with opposite motions, the one outside itself, the other within itself [62]-[64]). Lomonosov in his “Meditaciones de Caloris et Frigoris” in 1747 anticipated that the rotary calorific motion of warm bodies with faster spin repel each other with greater force in compare with the rotary frigoric motion of colder bodies [65],[66]. Rankine around the year 1850 proposed the elastic vortex of spinning atoms and molecules as the cause of heat [67]-[70].

These old anticipations of heat carriers we can express as the mixing of the hot thermons (“caloris”) with the cold thermons (“frigoris”) described by the very well-known Richmann mixing law [71] as (1).

$$N_A \frac{2\pi \hbar V_{HOT}}{T_{HOT}} \rightarrow 2N_A \frac{2\pi \hbar V_{MEAN}}{T_{MEAN}} \leftarrow N_A \frac{2\pi \hbar V_{COLD}}{T_{COLD}}$$

(1)

where $N_A$ is the Avogadro number. In this model the angular momentum of hot and cold thermons interact in order to achieve their equilibrium state between the hot and cold state.

The second property of the thermon is their elastic volume that is employed in the Carnot engines to do the volume work. Therefore, hot and cold thermons interact between each other and exchange their angular momentum and the elastic volume in order to achieve some final state between the hot and cold state.

We formulate a hypothesis that a certain temperature $T_X$ from the interval $T_{HOT} > T_X > T_{COLD}$ might evaluate the contributions of the elastic volume of thermons and the angular momentum of thermons. We propose that unknown $T_X$ is the point dividing the interval $\Delta T = T_{HOT} - T_{COLD}$ into two intervals: $(T_{HOT} - T_X)$ and $(T_X - T_{COLD})$ in an analogy with the known Golden mean $\Phi = 1.618$. The proposed characteristic temperatures $T_X$ are given in Table I.

<table>
<thead>
<tr>
<th>TABLE I: HYPOTHESIS OF THE CHARACTERISTIC TEMPERATURE DURING THE NEWTON’S COOLING EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden mean $\Phi = 1.618…$</td>
</tr>
<tr>
<td>$T_\Phi = T_{COLD} + \frac{T_{HOT} - T_{COLD}}{\Phi}$</td>
</tr>
<tr>
<td>Golden $e$ (Euler number) $e = 2.718…$</td>
</tr>
<tr>
<td>$T_e = T_{COLD} + \frac{T_{HOT} - T_{COLD}}{e}$</td>
</tr>
<tr>
<td>Golden 3</td>
</tr>
<tr>
<td>$T_3 = T_{COLD} + \frac{T_{HOT} - T_{COLD}}{3}$</td>
</tr>
<tr>
<td>Golden $\pi = 3.141…$</td>
</tr>
<tr>
<td>$T_\pi = T_{COLD} + \frac{T_{HOT} - T_{COLD}}{\pi}$</td>
</tr>
</tbody>
</table>

In order to select the most realistic $T_X$ we have to determine experimentally the time $\tau_X$ needed to achieve that temperature $T_X$. The cooling constant $1/\tau_X$ will be compared with the slope $\kappa$ of experimental data in the semi-log Newton’s cooling law calculated from the linear regression from all experimental points. The best fit will be used as the characteristic temperature of thermons and can be used to determine to ratio of contributions of the elastic volume of thermons and the angular momentum of thermons for the determination of the maximal efficiency of the Carnot engine and the Seebeck generator.

III. EXPERIMENTAL PART

The Newton’s cooling law was studied for the system water – air. The set of SIMAX borosilicate flasks, round bottom, narrow neck, with rim and volumes 100, 250, 500, 1000, and 2000 mL was used for those experiments. The starting temperature was 90° C, 80° C, and 70° C. The temperature of the surroundings was 24° C in the laboratory, and (4° ± 2°) C the outside temperature on March 05, 2023 near Prague. In order to get “true” Newton’s cooling data it is necessary to minimize contact of flasks with the laboratory stand via holders with cross clamps. In an ideal case the spherical flask should be surrounded by the air only as it was proposed and realized by Richmann in 1747 [2]. The second condition to get „true Newton’s cooling data” is to find the right position for thermometers as it was discussed by Davidson [22]. We have investigated four positions for the used thermometers: 1. bottom wall inside of the flask, 2. in the center of the flask, 3. near the surface of water in the flask, 4. outside bottom wall of the flask. The arrangement of these experiments is given in Fig. 1. The temperature was measured in 5 minutes intervals for two hours.
IV. RESULTS AND DISCUSSION

The Newton’s cooling law is usually described by (2):

\[
\ln \left( \frac{T(t) - T_{\text{env}}}{T_0 - T_{\text{env}}} \right) \approx \kappa t \approx \left[ \ln \left( \frac{1}{\tau_\kappa} \right) \right]
\]  

(2)

where \( T(t) \) is temperature at time \( t \), \( T_0 \) is temperature at time \( t = 0 \), \( T_{\text{env}} \) is temperature of the surrounding, \( \kappa \) is the cooling constant found from the linear regression of the semi-log graph of the experimental data.

In order to get the “true” Newton’s cooling data, the thermometer should be placed in touch with the inside bottom wall of the flask, other positions of the thermometer lead to the “false” Newton’s cooling data (caused by effects expressed in the Biot number and the Fourier number). Fig. 2 shows such data taken for the 2000 mL flask for \( T_0 = 90°C \) and \( T_{\text{env}} = 24°C \) and four different positions of thermometers. In order to get the “true” Newton’s cooling data the flask with water should be isolated from any contacts with the laboratory table or other instruments and in an ideal case the flask should be surrounded by the air only. The second condition is the right position of the thermometer on the inside bottom wall of the flask. In other case we will get “false” Newton’s cooling data that will result in different cooling constant \( \kappa \) values. Such data cannot reveal the hidden structure of thermons.

During the preliminary experiments we have determined the characteristic temperature \( T_x \) from the proposed temperatures \( T_\Phi \), \( T_c \), \( T_s \), and \( T_x \) given in Table I. The temperature \( T_x \) and its experimental time \( \tau_x \) to achieve temperature \( T_x \) fit the cooling constant \( \kappa \) with the best possible accuracy in these experiments.
Table II summarizes the experimentally found cooling constants $1/\tau_T$ for the temperature $T_e$ and $\kappa$ determined using the linear regression from the semi-log graph of experimental data set of temperatures measured at the inside bottom wall of the flask. The laboratory temperature was $T_{\text{env}} = 24.0^\circ \text{C}$.

<table>
<thead>
<tr>
<th>Mass of $\text{H}_2\text{O} [\text{g}]$</th>
<th>$T_{\text{env}} [^\circ \text{C}]$</th>
<th>$T_e [^\circ \text{C}]$</th>
<th>$T_\kappa [^\circ \text{C}]$</th>
<th>$1/\tau_T [\text{min}]$</th>
<th>$\kappa [\text{min}^{-1}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2100</td>
<td>24.0</td>
<td>90.0</td>
<td>45.0</td>
<td>-0.0080</td>
<td>-0.0078</td>
</tr>
<tr>
<td>2100</td>
<td>24.0</td>
<td>80.0</td>
<td>41.8</td>
<td>-0.0077</td>
<td>-0.0078</td>
</tr>
<tr>
<td>2100</td>
<td>24.0</td>
<td>70.0</td>
<td>38.6</td>
<td>-0.0074</td>
<td>-0.0074</td>
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<tr>
<td>1050</td>
<td>24.0</td>
<td>90.0</td>
<td>45.0</td>
<td>-0.0101</td>
<td>-0.0099</td>
</tr>
<tr>
<td>1050</td>
<td>24.0</td>
<td>80.0</td>
<td>41.8</td>
<td>-0.0095</td>
<td>-0.0095</td>
</tr>
<tr>
<td>1050</td>
<td>24.0</td>
<td>70.0</td>
<td>38.6</td>
<td>-0.0085</td>
<td>-0.0087</td>
</tr>
<tr>
<td>525</td>
<td>24.0</td>
<td>90.0</td>
<td>45.0</td>
<td>-0.0121</td>
<td>-0.0116</td>
</tr>
<tr>
<td>525</td>
<td>24.0</td>
<td>80.0</td>
<td>41.8</td>
<td>-0.0110</td>
<td>-0.0117</td>
</tr>
<tr>
<td>525</td>
<td>24.0</td>
<td>70.0</td>
<td>38.6</td>
<td>-0.0100</td>
<td>-0.0105</td>
</tr>
<tr>
<td>280</td>
<td>24.0</td>
<td>90.0</td>
<td>45.0</td>
<td>-0.0151</td>
<td>-0.0140</td>
</tr>
<tr>
<td>280</td>
<td>24.0</td>
<td>80.0</td>
<td>41.8</td>
<td>-0.0141</td>
<td>-0.0132</td>
</tr>
<tr>
<td>280</td>
<td>24.0</td>
<td>70.0</td>
<td>38.6</td>
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<td>-0.0134</td>
</tr>
<tr>
<td>125</td>
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<td>90.0</td>
<td>45.0</td>
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<tr>
<td>125</td>
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<td>80.0</td>
<td>41.8</td>
<td>-0.0169</td>
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<tr>
<td>125</td>
<td>24.0</td>
<td>70.0</td>
<td>38.6</td>
<td>-0.0159</td>
<td>-0.0157</td>
</tr>
</tbody>
</table>

Table III summarizes the experimentally found cooling constants $1/\tau_T$ for the temperature $T_e$ and $\kappa$ determined using the linear regression from the semi-log graph of experimental data set of temperatures measured at the inside bottom wall of the flask. The outdoor temperature was slightly oscillating in the range $T_{\text{env}} = (4.0^\circ \pm 2.0^\circ) \text{C}$ under a slight wind flowing conditions (this outdoor experiment was done on March 05 2023 close to Prague).

<table>
<thead>
<tr>
<th>Mass of $\text{H}_2\text{O} [\text{g}]$</th>
<th>$T_{\text{env}} [^\circ \text{C}]$</th>
<th>$T_e [^\circ \text{C}]$</th>
<th>$T_\kappa [^\circ \text{C}]$</th>
<th>$1/\tau_T [\text{min}]$</th>
<th>$\kappa [\text{min}^{-1}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1050</td>
<td>4.0 ± 2.0</td>
<td>90.0</td>
<td>31.4</td>
<td>-0.0122</td>
<td>-0.0126</td>
</tr>
<tr>
<td>1050</td>
<td>4.0 ± 2.0</td>
<td>80.0</td>
<td>28.2</td>
<td>-0.0120</td>
<td>-0.0125</td>
</tr>
<tr>
<td>1050</td>
<td>4.0 ± 2.0</td>
<td>70.0</td>
<td>25.0</td>
<td>-0.0118</td>
<td>-0.0125</td>
</tr>
<tr>
<td>525</td>
<td>4.0 ± 2.0</td>
<td>90.0</td>
<td>31.4</td>
<td>-0.0164</td>
<td>-0.0153</td>
</tr>
<tr>
<td>525</td>
<td>4.0 ± 2.0</td>
<td>80.0</td>
<td>28.2</td>
<td>-0.0135</td>
<td>-0.0146</td>
</tr>
<tr>
<td>525</td>
<td>4.0 ± 2.0</td>
<td>70.0</td>
<td>25.0</td>
<td>-0.0130</td>
<td>-0.0137</td>
</tr>
<tr>
<td>280</td>
<td>4.0 ± 2.0</td>
<td>90.0</td>
<td>31.4</td>
<td>-0.0179</td>
<td>-0.0188</td>
</tr>
<tr>
<td>280</td>
<td>4.0 ± 2.0</td>
<td>80.0</td>
<td>28.2</td>
<td>-0.0175</td>
<td>-0.0177</td>
</tr>
<tr>
<td>280</td>
<td>4.0 ± 2.0</td>
<td>70.0</td>
<td>25.0</td>
<td>-0.0175</td>
<td>-0.0183</td>
</tr>
<tr>
<td>125</td>
<td>4.0 ± 2.0</td>
<td>90.0</td>
<td>31.4</td>
<td>-0.0244</td>
<td>-0.0251</td>
</tr>
<tr>
<td>125</td>
<td>4.0 ± 2.0</td>
<td>80.0</td>
<td>28.2</td>
<td>-0.0232</td>
<td>-0.0230</td>
</tr>
<tr>
<td>125</td>
<td>4.0 ± 2.0</td>
<td>70.0</td>
<td>25.0</td>
<td>-0.0217</td>
<td>-0.0230</td>
</tr>
</tbody>
</table>

V. THE CARNOT ENGINE AND THE SEEBAEK GENERATOR

The two features of thermons: their elastic volume and their angular momentum offer a new possibility to define efficiencies of the Carnot engine [72],[73] and the Seebeck generator [74],[75]. The available heat Q can be partly used in the Carnot engine as the “useful” heat to transfer it into volume work (thermon elastic volume) and the “waste” heat can be transformed in the Seebeck generator into electricity (thermon angular momentum activates electrons), as shown in (3).

$$Q = C_p (T_{\text{HOT}} - T_{\text{COLD}}) = C_p (T_{\text{HOT}} - T_e) + C_p (T_e - T_{\text{COLD}})$$  \hspace{1cm} (3)

where $C_p$ is the molar specific heat at the constant pressure. The total efficiency for the Carnot engine and the Seebeck generator can be calculated using (4).

$$\eta = \frac{T_{\text{HOT}} - T_e}{T_{\text{HOT}} - T_{\text{COLD}}} + \frac{T_e - T_{\text{COLD}}}{T_{\text{HOT}} - T_{\text{COLD}}} = \left(1 - \frac{1}{\pi}\right) + \left(\frac{1}{\pi}\right) \approx 0.682 + 0.318$$  \hspace{1cm} (4)

This Carnot – Seebeck combined engine enables to convert all available heat into the volume work and into the electricity.
VI. THE HISTORICAL NEWTON’S COOLING DATA ANALYZED BY GRIGULL AND MARUYAMA AND MORIYA

The Newton’s historical cooling data [1] were analyzed many times by scholars in the past time. We will try to apply our model on the Newton’s data analyzed by Grigull [10], and by Maruyama and Moriya [25]. Table IV summarizes experimental data of Newton in the form of the modern estimation of temperatures by Grigull [10] and discussed by Maruyama and Moriya [25].

<table>
<thead>
<tr>
<th>TIME [min]</th>
<th>NEWTON [° C]</th>
<th>GRIGULL [° C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>429.41</td>
<td>631</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>561</td>
</tr>
<tr>
<td>7</td>
<td>335.29</td>
<td>420</td>
</tr>
<tr>
<td>13</td>
<td>282.35</td>
<td>327</td>
</tr>
<tr>
<td>17</td>
<td>238.24</td>
<td>271</td>
</tr>
<tr>
<td>21</td>
<td>205.88</td>
<td>232</td>
</tr>
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<td>27</td>
<td>167.65</td>
<td>187</td>
</tr>
<tr>
<td>32</td>
<td>138.24</td>
<td>151</td>
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<tr>
<td>38</td>
<td>118.71</td>
<td>135</td>
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<tr>
<td>45</td>
<td>97.06</td>
<td>100</td>
</tr>
<tr>
<td>78</td>
<td>35.29</td>
<td>37</td>
</tr>
</tbody>
</table>

Both Newton’s data and the Grigull’s modern data are depicted in Fig. 3. It is seen that the characteristic temperature \( T_\pi \) and the time \( \tau_\pi \) can reasonably model the cooling constant \( \kappa \) even for the temperature interval \( \Delta T \approx 600 \) K.

VII. CONCLUSION

At its origins, thermodynamics was the study of heat and engines. This science made the great progress during the past three hundred years but still some topics should be discussed in our epoch, too. The very well-known Newton’s cooling law can be newly interpreted using the model of thermons – carriers of heat.

1. The Newton’s cooling law was experimentally studied in details during past three centuries but there might be still some hidden information for our generation.
2. The system water – air was experimentally studied using the simple high school equipment.
3. There was found a characteristic temperature \( T_\pi \) that might fit the observed semi-log dataset with a reasonable accuracy.
4. This new characteristic temperature \( T_\pi \) was used to estimate the efficiency of the Carnot heat engine and the Seebeck generator based on the contributions of the thermon elastic volume and the thermon angular momentum.
5. This model predicts the conversion of the “useful” heat into the volume work (Carnot in 1824, elastic volume of thermons) and the conversion of the “waste” heat into electricity (Seebeck in 1825, angular momentum of thermons activates electrons).
6. The historical Newton’s cooling data [1] analyzed by Grigull [10], and Maruyama and Moriya [25] confirm this presented model very well even for the interval \( \Delta T = 600 \) K.
ACKNOWLEDGMENT

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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