Gottfried Erich Rosenthal (1745–1813), a follower of Deluc in northern Germany

Geneva (372 m) seen from the Salève (1379 m)

Brecken (1141 m) seen from Wernigerode (240 m)

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Gottfried Erich Rosenthal (1745–1813) was born and died at Nordhausen (now in Thuringia). As his ancestors, he became a Master-Baker after his studies at the local Gymnasium, where he excelled in mathematics. In 1779, after reading the 1772 treatise by Deluc, he became interested in meteorology, building and selling (even to Goethe) thermometers and “improved” barometers, and using them to measure elevations, notably of the near Brocken.

For the temperature correction of the barometer readings, he graduated his mercury thermometer (one is preserved at Lausanne) with four uncommon scales. In 1787, three years after finishing his monumental “Beyträge…”, where he described his instruments and his hypsometric measurements, he gave up meteorology, for unknown reasons.
How high are these mountains?

We’ll see how it is possible to measure rather precisely the elevation of a mountain, between two stations, using two *clocks*, a pair of mercury *barometers*, as well as a pair of *thermometers* to correct the barometer readings and to take into account the temperature of the column of air between the two stations.

**Summary:**

- Rosenthal’s mercury thermometer at Lausanne
  - G. E. Rosenthal’s life and works
  - Rosenthal’s siphon mercury barometer
- Rosenthal thermometer’s scales, temperature scales and thermometer’s calibration
  - Barometric hypsometric measurements: the Brocken
    - Conclusions and acknowledgements
      - Selected bibliography
- Appendix 1: Conversion of temperature scales: exact formulas
  - Appendix 2: Mercury barometer: temperature correction
  - Appendix 3: Rosenthal siphon barometer: how to use it as a thermometer
A mysterious-looking mercury thermometer

Top:
Rosentals Scalen
Beýträge No. IV
Hg tube too short?

Middle:
4 unknown scales
$T_{\text{ref}}$?

Bottom:
Hg bulb

UNIL – Musée de physique – Inv. 603.096
Gottfried Erich ROSENTHAL (1745–1813)

• Born and died at Nordhausen, Imperial Free City until 1807
• Studies at the local Gymnasium, gifted for mathematics
• Becomes a “Meister Bäcker”, as his forebears since 1570 and later family members until 1923
• Prefers to study, becomes a land surveyor, publishes in 1772 a “Comparison of weights and measures used at Nordhausen and elsewhere”
• 1779–1787: Meteorological period, makes and sells barometers and thermometers From 1780, probably no more active as a baker
• 1788–1808: publishes a large number of (deservedly forgotten) literary-scientific-technical works of encyclopedic character
ROSENTHAL’s meteorological period (1779–1787)

Reads the book *Modifications de l’atmosphère* (Genève 1772) of Jean-André Deluc (Geneva 1727–England 1817), becomes interested in meteorology

- Builds an “improved” version of Deluc barometer
- Also makes thermometers, sells them to such luminaries as Goethe
- Publishes his meteorological observations
- As Deluc, interested in *measuring differences of elevation by means of a barometer:* he ascends the Brocken in 1780
- 1782 and 1784: Publication of his opus magnum *Beüträge zur der Verfertigung, der wissenschaftlichen Kenntniß, und dem Gebrauche meteorologischer Werkzeuge*  
  
  Bd. 1: Barometers and thermometers, barometric hypsometry (>330 p.)
  Bd. 2: Barometric hypsometry (>350 p.)
Rosenthal’s mercury barometer

Deluc: *first to boil the mercury!*

=> Reproducible measurements

- Transportable siphon barometer, as Deluc’s
- Tube of *uniform bore* fixed on a wood plank
- Reading on 2 brass scales with movable indices

\[ H = H_2 - H_1 \]

- The scales: *decimal* graduation in “scruples”
  
  1 scr = 1/16 line = 1/(12x12x16) “pied de Roi”

  => 1 scr ≈ 0.141 mm

- Thermal expansion of Hg (density) and of support (linear) cannot be neglected!

But a separate thermometer is *not* needed, this barometer displays its own temperature!

\[ H_2 + H_1 \sim T \]

*Beüträge*, Bd. 1, Fig. 1 & 2, S. 36
Rosenthal’s mercury thermometer: the 4 scales

$T_{bw} = 1272 = 100 \, ^\circ C$

**“Neue Skale”** (new scale): the only **temperature** scale, from 864 (bottom, $-18.6^\circ C$) to 1272 (top, “Kochpt. des Waßers”)

**“Meteorologische Berichtigungs Skale”** (meteorological correction scale): From +34 (bottom) to –68 (top) Shows the number of **scruples** by which a column of Hg of length $H_{ref} (= 5184 \, scr = 27'')$ expands or contracts when not at the reference temperature $T_{ref} = 1000 \approx 20.9^\circ C$

=>$\alpha_{barom} = 165.9 \, e^{-6/\circ C}$
(true value for Hg alone $180.2$)

$T_{ref} = 1000$

**“Multipl. Skale”** (multiplication scale $M$): a measurement of the thermal expansion of Hg, used for the reduction of $H$ at $T$ to $H_t$ at $T_{ref}$

$H_t = H \cdot M(T)$
$M = 1$ at $T_{ref}$

**“Logarithm. Skale”**: $1e7 \cdot \log_{10} M(T)$ Simplifies the reduction of $H$ to $H_t$
Multiplication $\Rightarrow$ addition, if Log table available

*Beüträge, Bd. 1, Fig. 3, S. 36*
Comparison of a few temperature scales

1. Modern Celsius: Two fixed points (formerly Centigrade)

2. Réaumur: Two fixed points
   Was in common use on the Continent

3. J. H. Lambert ("Pyrometrie", 1779) studies Air Thermometers
   One fixed point ($T_{fw} = 1000$
   A volume of air of 1000 at $T = T_{fw}$
   expands to 1370 at $T = T_{bw}$
   => $T_{bw}$ (Lambert) = 1370

   Lambert (and later Rosenthal) were convinced that the air thermometer shows the true degree of heat.

   But they don’t comment on the extrapolation of their scales to 0: 0 (Lambert, Rosenthal) ≈ −270 °C!

4. Rosenthal mercury thermometer
   "Neue Skale" like Lambert’s, but
   $T_{ref} = 1000$ (≈ 20.9 °C) and $T_{fw} = 928
Lausanne thermometer (Inv. 603.096): calibration

The mercury tube has been replaced!
Barometric hypsometric measurements: formulas

Empirical value: $\Delta h = 15 \text{ to } 10 \text{ m/mmHg}$

E. Halley (1686) proposed: $\Delta h = K \cdot \log \left( \frac{H_0}{H} \right)$

but his formula was not accepted

J.-A. Deluc confirmed experimentally the validity of Halley’s formula, ascending the mountains in the Alps around Geneva, especially the Salève, of elevation above the lake already measured geometrically.

He was the first to introduce a correction for the temperature of the column of air, by means of its mean value. He published his results in his influential treatise of 1772, 2nd edition in 1784.

Rosenthal, using his « absolute » air temperature scale, uses:

$$\Delta h = K \cdot \left[ \frac{(T_0 + T)}{2000} \right] \cdot \log \left( \frac{H_0}{H} \right)$$

$K \approx 10'000$ when $\Delta h$ is measured in toises

(1 toise = 6 “pieds de Roi” $\approx 1.949 \text{ m}$)
Barometric hypsometric measurements: procedure

<table>
<thead>
<tr>
<th>Location</th>
<th>$h = 0$</th>
<th>$h = X &gt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>$t, H_{10}, H_{20}, T_0$</td>
<td>$t, H_1, H_2, T$</td>
</tr>
<tr>
<td>Calculate</td>
<td>$\alpha_0 = H_{10} - H_{20}$</td>
<td>$&lt; T &gt; = (T_0 + T)/2$</td>
</tr>
<tr>
<td></td>
<td>$\beta_0 = H_{10} + H_{20}$</td>
<td>$\alpha = H_1 - H_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\beta = H_1 + H_2$</td>
</tr>
<tr>
<td>Formulas</td>
<td>$H_0 = L \cdot \alpha_0 / \beta_0$</td>
<td>$H_0/H = (\alpha_0 \cdot \beta) / (\beta_0 \cdot \alpha)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$H = L \cdot \alpha / \beta$</td>
</tr>
<tr>
<td>Use logs table</td>
<td></td>
<td>+ $\log \alpha_0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- $\log \beta_0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ $\log \beta$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- $\log \alpha$</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>$X_{\text{raw}} / 10^3$</td>
</tr>
<tr>
<td>Elevation in toises</td>
<td></td>
<td>$X = 10 \cdot &lt; T &gt; \cdot X_{\text{raw}}$</td>
</tr>
</tbody>
</table>

$t$: time, the same for the 2 locations  
$H$: barometric readings (arbitrary units)  
$T$: air temperature (Rosenthal’s “Neue Skale”)  
($L$: total (constant) length of the mercury column at $T = T_{\text{ref}}$)
Rosenthal’s barometric hypsometric measurements

Rosenthal ascends the Brocken in July 1780, takes many measurements, one observer remaining at Nordhausen.

Itinerary, stations not precisely known.

\[ \Delta h \text{ (Nordhausen–Brocken)} = 488 \text{ toises} = 951.2 \text{ m} \]

\[ 180 \text{ m} < h_{\text{Nordhausen}} < 220 \text{ m} \]

\[ \Rightarrow h_{\text{Brocken}} \approx 1151 \text{ m} \] (actually 1141 m)
Conclusions

• Best hypsometric accuracy obtained by triangulation, either terrestrial (theodolite) or celestial (satellites such as GPS).

• Barometric elevation measurements remain of limited precision, but are nowadays done quickly with simple instruments (no more mercury!): thus still used for navigation above earth (gliders, ballooning, ...) or where GPS does not reach: in deep canyons, inside buildings, under earth, ...

• G. E. Rosenthal was not a genius, but a rather eccentric character who brought an original contribution to meteorology, far from important scientific centers:
  — decimal barometric scale,
  — self-correcting barometer (Hg temperature),
  — “absolute” air temperature scale,
  — elevation calculations simplified by using logarithms.
Acknowledgements

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I am also grateful to the EPFL, through my laboratory, the LPHE, for its continued support.
Selected bibliography


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— M. ARCHINARD: *De Luc et la recherche barométrique* (MHS Genève, 1980)

Life & Work of G. E. Rosenthal:

— J. C. POGGENDORFF: *Biographisch-Literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften, Bd. II, S. 696-7*


### App. 1: Conversion of temperature scales: exact formulas

<table>
<thead>
<tr>
<th>Scale $s$</th>
<th>Temperature $t$ / °C</th>
<th>$T_{fw}$ / °C</th>
<th>$T_{bw}$ / °C</th>
<th>$s = 0$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Lambert (air)</td>
<td>$(s - 1000) \cdot 10/37$</td>
<td>1000</td>
<td>1370</td>
<td>≈ −270</td>
</tr>
<tr>
<td>2 Rosenthal NS</td>
<td>$(s - 928) \cdot 25/86$</td>
<td>928</td>
<td>1272</td>
<td>≈ −270</td>
</tr>
<tr>
<td>3 Réaumur</td>
<td>$s \cdot 5/4$</td>
<td>0</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>4 Fahrenheit</td>
<td>$(s - 32) \cdot 5/9$</td>
<td>32</td>
<td>212</td>
<td>≈ −17.8</td>
</tr>
<tr>
<td>5 Celsius (original)</td>
<td>$100 - s$</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>6 Christin or “de Lyon”</td>
<td>$s$</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>7 Delisle (or de Lisle)</td>
<td>$100 - (2s / 3)$</td>
<td>150</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>8 Deluc (or De Luc) − 186 div.</td>
<td>$(s + 39) \cdot 50/93$</td>
<td>−39</td>
<td>147</td>
<td>≈ 21</td>
</tr>
<tr>
<td>9 Deluc − 96 div.</td>
<td>$(s + 12) \cdot 25/24$</td>
<td>−12</td>
<td>84</td>
<td>12.5</td>
</tr>
<tr>
<td>10 Rosenthal MBS</td>
<td>$(18 - s) \cdot 50/43$</td>
<td>+18</td>
<td>−68</td>
<td>≈ 20.9</td>
</tr>
</tbody>
</table>

### 1 to 8: True temperature scales

The Fahrenheit scale was and still is in common use.  
The Delisle scale was also fairly common, besides many other scales.  
The original centesimal Celsius scale (100 to 0) was reversed by Christin (from Lyon) to become the ancestor of the modern Centigrade, now Celsius scale.

### 9 and 10: Barometer height correction scales,

based on the thermal expansion of mercury, as proposed by Deluc and Rosenthal.
App. 2: Mercury Barometer: temperature correction

Barometer readout $H = H_2 - H_1$ depends on
- the mercury density (or the thermal expansion per unit of volume),
- the linear expansion of the scale (wood, later brass, ...),
both functions of temperature.

Last quarter of the XVIIIth c.:
Rough measurements of the expansion of a Hg column of length $H_{\text{ref}}$ at $T_{\text{ref}}$
in situ in the barometer, in a very limited range of temperatures

Deluc:
$\Delta H = \frac{96}{16}$ line on $H_0 = 27''$ (extrapolated 0°C to 100°C) => $\alpha_{\text{barom}} = 182.5 \times 10^{-6}/^\circ C$
Interval 0°C to 100°C divided in 96 parts (1/16 line), centered on $T_{\text{ref}} = 12.5^\circ C$
Scale directly used for the correction (graphical method)

Rosenthal:
$\Delta H = \frac{86}{16}$ line (27'', 0°C to 100°C) => $\alpha_{\text{barom}} = 165.9 \times 10^{-6}/^\circ C$
Interval 0°C to 100°C divided in 86 parts (“scruples”), centered on $T_{\text{ref}} = 20.9^\circ C$
Scale not used for actual correction during his trips with his siphon barometer!
For barometers with two tubes of different diameters, or for cistern barometers,
Rosenthal prefers the arithmetic calculation based on $M$ and $\log M$

First barometer with a complete movable brass scale: A. Pictet, Geneva 1803

The cathetometer invented by Dulong and Petit in the early XIXth c., allows precise
laboratory measurements of thermal expansion in a wide range of temperatures:
1817: $\alpha_{\text{Hg}} = 180.18 \times 10^{-6}/^\circ C$ Brass: 18.4 $\times 10^{-6}$ Wood $\approx 5.5 \times 10^{-6}$ (pine)
App. 3: Rosenthal’s siphon barometer: it can be used as a thermometer!

\[ H_2 + H_1 = L \ (1 + \alpha \cdot \Delta T) \]

\(H_2\) and \(H_1\) are the long arm and the short arm barometer readings
\(L\) is the total length of the mercury column, at \(T = T_{\text{ref}}\);
it’s a constant for a given barometer
\(\alpha\): thermal expansion coefficient of mercury (per unit of volume)
\(\Delta T = T - T_{\text{ref}}\), where \(T_{\text{ref}}\) is some fixed reference temperature

\(H\) is the true barometer height, reduced at \(T = T_{\text{ref}}\):
\[ H_2 - H_1 = H (1 + \alpha \cdot \Delta T) \]
\[
\frac{(H_2 - H_1)}{H} = \frac{(H_2 + H_1)}{L}
\]
\[ H = L \cdot \frac{(H_2 - H_1)}{(H_2 + H_1)} \]

Halley and De Luc: calculate the ratio \(H_0\) (at \(h = 0\)) over \(H\) (at \(h = X\)):
\(L\) and \(\alpha\) disappear!
c.q.f.d.