EQUIPMENT USAGE NOTE

Analogue barometer

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The mercury barometer

Summary

Barometers are instruments used to measure atmospheric pressure, and have a rich history of technological development due to the correlation between variations in pressure and changes in weather. The importance of predicting weather, especially during the age of sail cannot be overemphasised, which in great part spurred many developments in our understanding of thermodynamics and its applications, along with clever and robust technologies and instruments to measure quantities of interest. One such example is the mercury barometer, a device for providing an accurate measurement of atmospheric pressure.

The device

This particular barometer is a construction of Haratio Yeates of 97 Collins Street, Hobart and was completed on 05/08/1896. At its core, it is a mercury barometer which is used to measure the local pressure. Due to the age of the device, the units of measurement are antiquated, and to extract an accurate measurement, corrections must applied to the measured value.

How does it function?

Traditional barometers function on the principle of equilibrium: the force exerted on an area of fluid by the atmosphere is balanced by the weight of the same fluid in a restricted vessel. Specifically, a tube sealed at one end with a diameter smaller than that of the reservoir is inserted into the reservoir such that the liquid is free to flow from the reservoir into the tube. If the instrument is initialised with the tube full of liquid, following submersion, a vacuum will be created above the fluid and an the fluid will settle at a height when the weight of the fluid column exerted on the reservoir is equal to that of the pressure exerted by the atmosphere, meaning that a measurement the height of the fluid is a proxy measurement of the pressure.

In order to achieve a more accurate measurement, an additional mechanism to compensate for the displacement of mercury between the reservoir and the tube under different pressures is included. This has the benefit of allowing much smaller liquid reservoirs, but payment comes in the form of an additional measurement: the reference level of the reservoir must be set prior to reading the height of the liquid.

A limitation of barometers comes in the form that whilst we are interested in measuring the pressure, our system will respond to other environmental parameters, notably temperature, and thus in order to collect an accurate measurement of pressure, care must be taken to simultaneously record the temperature and pressure, and apply the appropriate corrections. Moreover, the location of the barometer will influence the measured pressure: the altitude of the device, along with the local gravitation potential will influence the measurement.

Exercise 1

You will likely be aware that barometers typically use mercury as the liquid to produce pressure readings. What is the reason for this?

Solution 1

The pressure differential ΔP between the atmosphere and the vacuum (or near vacuum) at the top of the barometer is related to the difference in height h, the density of the fluid ρ and the acceleration due to gravity g through $\Delta P = \rho g h$. Recast, the height of the fluid column will be given by

$$h = \frac{\Delta P}{\rho g} \tag{1}$$

and thus to have a "small"-sized column, one wants to use the highest density liquid possible, and with a density of 13.6 g/cm^{-3} mercury is the liquid with the highest density. Unfortunately, mercury is acutely toxic and consequently, mercury is not commonly used in mordern scientific instrumentation (indeed, it is banned in the European Union) and friendlier *heavy fluids* are used, such as Sodium metatungstate, but with a density of only 3.1 g/cm^{-3}, a barometer would need to be over four times the height to measure an equivalent pressure differential. This is still better than water, which would need to be 13.6 times the height!

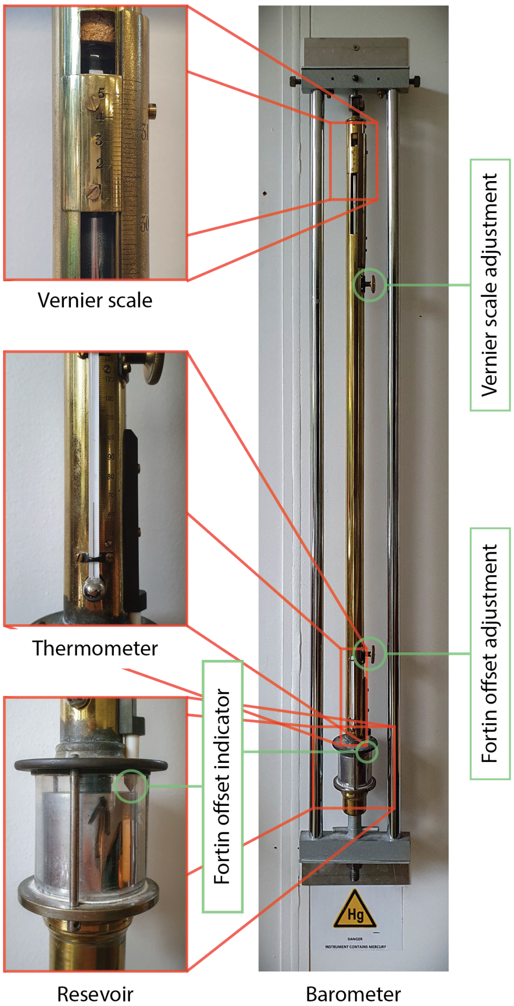

Figure 1: The Fortin barometer with identified components.

The level of care that must be applied when correcting the measured pressure depends on the measurement uncertainty, as there is no point correcting for the local gravitation potential, which alters a measurement by approximately 0.5%, if you have a relative uncertainty of the order of 10%. All correction formulae are provided below, and a detailed discussed of their origins can be found elsewhere [1], along with published tables of corrections [2].

Note that the physics lab has a location described by the latitude and longitude values (-42.90366, 147.32738), and the altitude is estimated as 31.54 m above the mean sea level.

Temperature correction

The correction C_T which corrects for the effects of temperature a T in in Fahrenheit is given by:

$$C_T = P_T - P_m = P_m \left(\frac{1 + L(T - 62)}{1 + M(T - 32)} - 1 \right) \tag{2}$$

where P_T is the temperature corrected reading, P_m is the measured value, and the correction factors are $L = 1.02 \times 10^{-5}\,{}^\circ\mathrm{F}^{-1}$ and $M = 10.10 \times 10^{-}5\,{}^\circ\mathrm{F}^{-1}$.

Gravity correction

The correction C_g which corrects for variation is gravity can be approximated at a given angle of latitude φ by

$$C_g = P_l - P_T = P_T \left(\frac{980.616}{980.665} \left(1 - \frac{2637.3 \cos(2\varphi) + 5.9 \cos^2(2\varphi)}{10^6} \right) - 1 \right) \tag{3}$$

and yielding P_l, the local pressure.

Altitude correction

The pressure as measured at altitude can be corrected by calculating the pressure differential ΔP_s:

$$\Delta P_s = P_0 \left(1 - \left(1 - \frac{6.5 \times 10^{-3}}{288.16} H \right)^{5.2561} \right) \tag{4}$$

where $P_0 = 29.921\,\mathrm{inchesHg}$ is the standard pressure at sea level and H is the geopotential height in metres, which can be approximated by the elevation above sea level.

How does one drive it?

The mode of pressure measurement is both formulaic and straightforward:

1. Set the reservoir reference level. Use the knurled knob at the base of the instrument to set the ivory pointer so that the tip is touching the surface of the mercury.
2. Measure the height of the mercury column. Use the knurled knob at the top of the instrument to position the bottom of the Vernier scale in line with the top of the mercury meniscus. Operating with care to avoid parallax error, record the height of the mercury column from the Vernier scale.
3. Record the temperature using the mounted thermometer, use relevant formulae to correct and convert the measurement.

References

[1] LP Harrison. Manual of barometry. *US Dept. of Commerce, Weather Bureau, Washington, DC*, 1963.

[2] Robert J List. Smithsonian meteorological tables. 1968.

Additional resources

- POLUS is a resource for all things related to experimental physics at UTAS

Pressure chapter correction due to temperature

The table 1 is a reproduced version of *TABLE VIII (c)* in the previous barometer documentation, providing the temperature correction to the barometer reading. Note that the correction is to be subtracted in every case.

Temp [° F]	Pressure [inches Hg]										
	26.0	**26.5**	**27.0**	**27.5**	**28.0**	**28.5**	**29.0**	**29.5**	**30.0**	**30.5**	**31.0**
30	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004
31	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007
32	0.008	0.008	0.008	0.008	0.009	0.009	0.009	0.009	0.009	0.009	0.009
33	0.010	0.010	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.012	0.012
34	0.013	0.013	0.013	0.013	0.014	0.014	0.014	0.014	0.015	0.015	0.015
35	0.015	0.015	0.016	0.016	0.016	0.017	0.017	0.017	0.017	0.018	0.018
36	0.017	0.018	0.018	0.018	0.019	0.019	0.019	0.020	0.020	0.020	0.021
37	0.020	0.020	0.021	0.021	0.021	0.022	0.022	0.022	0.023	0.023	0.024
38	0.022	0.023	0.023	0.023	0.024	0.024	0.025	0.025	0.026	0.026	0.026
39	0.024	0.025	0.025	0.026	0.026	0.027	0.027	0.028	0.028	0.029	0.029
40	0.027	0.027	0.028	0.028	0.029	0.030	0.030	0.031	0.031	0.032	0.032
41	0.290	0.030	0.030	0.031	0.031	0.032	0.033	0.033	0.034	0.034	0.035
42	0.032	0.032	0.033	0.033	0.034	0.035	0.035	0.036	0.036	0.037	0.038
43	0.034	0.035	0.035	0.036	0.036	0.037	0.038	0.038	0.039	0.040	0.040
44	0.036	0.037	0.038	0.038	0.039	0.040	0.040	0.041	0.042	0.043	0.043
45	0.039	0.039	0.040	0.041	0.042	0.042	0.043	0.044	0.045	0.045	0.046
46	0.041	0.042	0.043	0.043	0.044	0.045	0.046	0.047	0.047	0.048	0.049
47	0.043	0.044	0.045	0.046	0.047	0.048	0.048	0.049	0.050	0.051	0.052
48	0.046	0.047	0.047	0.048	0.049	0.050	0.051	0.052	0.053	0.054	0.054
49	0.048	0.049	0.050	0.051	0.052	0.053	0.054	0.055	0.055	0.056	0.057
50	0.050	0.051	0.052	0.053	0.054	0.055	0.056	0.057	0.058	0.059	0.060
51	0.053	0.054	0.055	0.056	0.057	0.058	0.059	0.060	0.061	0.062	0.063
52	0.055	0.056	0.057	0.058	0.059	0.060	0.061	0.062	0.064	0.065	0.066
53	0.057	0.059	0.060	0.061	0.062	0.063	0.064	0.065	0.066	0.067	0.068
54	0.060	0.061	0.062	0.063	0.064	0.065	0.067	0.068	0.069	0.070	0.071
55	0.062	0.063	0.064	0.065	0.067	0.068	0.069	0.071	0.072	0.073	0.074
56	0.064	0.066	0.067	0.068	0.069	0.070	0.072	0.073	0.074	0.076	0.077
57	0.067	0.068	0.069	0.071	0.072	0.073	0.075	0.076	0.077	0.078	0.080
58	0.069	0.071	0.072	0.073	0.074	0.076	0.077	0.078	0.080	0.081	0.082
59	0.072	0.073	0.074	0.076	0.077	0.078	0.080	0.081	0.083	0.084	0.085
60	0.074	0.075	0.077	0.078	0.080	0.081	0.082	0.084	0.085	0.087	0.088
61	0.076	0.078	0.079	0.080	0.082	0.084	0.085	0.087	0.088	0.090	0.091
62	0.079	0.080	0.082	0.083	0.085	0.086	0.088	0.089	0.091	0.092	0.094
63	0.081	0.083	0.084	0.086	0.087	0.089	0.090	0.092	0.093	0.095	0.096
64	0.083	0.085	0.086	0.088	0.090	0.092	0.093	0.095	0.096	0.097	0.099
65	0.086	0.088	0.089	0.091	0.092	0.094	0.095	0.097	0.099	0.101	0.102
66	0.088	0.090	0.081	0.093	0.095	0.097	0.098	0.100	0.101	0.103	0.105
67	0.090	0.092	0.094	0.096	0.097	0.099	0.101	0.102	0.104	0.106	0.108
68	0.093	0.095	0.096	0.098	0.100	0.102	0.103	0.105	0.107	0.109	0.110
69	0.095	0.097	0.099	0.101	0.102	0.104	0.106	0.108	0.110	0.112	0.113
70	0.097	0.099	0.101	0.103	0.105	0.107	0.109	0.111	0.112	0.114	0.116
71	0.100	0.102	0.103	0.105	0.107	0.109	0.111	0.113	0.115	0.117	0.119
72	0.102	0.104	0.106	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122
73	0.104	0.106	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122	0.124
74	0.107	0.109	0.111	0.113	0.115	0.117	0.119	0.121	0.123	0.125	0.127
75	0.109	0.111	0.113	0.115	0.117	0.120	0.122	0.124	0.126	0.128	0.130
76	0.111	0.113	0.116	0.118	0.120	0.122	0.124	0.126	0.128	0.131	0.133
77	0.114	0.116	0.118	0.120	0.122	0.125	0.127	0.129	0.131	0.134	0.136
78	0.116	0.118	0.120	0.123	0.125	0.127	0.129	0.132	0.134	0.136	0.138
79	0.118	0.121	0.123	0.125	0.127	0.130	0.132	0.135	0.137	0.139	0.141

Table 1: *Temperature correction to barometers of the Fortin Pattern.* Applicable to readings of Mercury barometers of the Fortin pattern, with brass scales extending from the cistern to the top of the mercury column to reduce them to 32° F.