

The diving medical detectives:
when diving medicine books
are completely wrong
02.02.2023, Part V:
On pressure units

Miri Rosenblat, TAU

Nurit Vered, Technion Haifa

Albi Salm, SubMarineConsulting

DOI:

The diving medical detectives: when diving medicine books are completely wrong, Part V: On pressure units

Abstract & Methods: the same, as per Parts I to IV of this series.

Part I, Ref. [1], DOI: [10.13140/RG.2.2.15199.79528](https://doi.org/10.13140/RG.2.2.15199.79528)

Part II, Ref. [2], DOI: [10.13140/RG.2.2.35722.39366](https://doi.org/10.13140/RG.2.2.35722.39366)

Part III, Ref. [3], DOI: [10.13140/RG.2.2.28043.62245](https://doi.org/10.13140/RG.2.2.28043.62245)

Part IV, Ref. [4], DOI: [10.13140/RG.2.2.12077.97760](https://doi.org/10.13140/RG.2.2.12077.97760)

If you want to contribute s.th. to our list, we would be very happy if you send an e-mail to our head of lab: director@smc-de.com

(That is: to be continued in 2023 with Part VI 😊)

The diving medical detectives: when diving medicine books are completely wrong, Part V: On pressure units

Here, in Part V, we give only a short comment about pressure units and the various conversion factors used in diving medicine books, as the majority of these books are using imperial units like pounds per square inch (psi) or feet of seawater (fsw), but for serious scientific publications or technical documentation the SI system, the „International System of Units“ is the preferred and used system.

These conversion factors are regularly not consistent over all these books as they normally do not specify (water-)temperature nor the density. So they are at times even contradicting and one thing for sure for a physician, i.e. a physical layman: confusing!

For an easy and quick assessment with mental arithmetic, say for a ballpark to check absolute pressures, partial pressures of oxygen and the like, especially when required underwater, during real diving, SI is the system of choice.

The mother of all diving manuals world-wide,
the United States Navy Diving Manual, with the very wise
remark, that 10 m is not 10 msw and: 10 feet is not 10 fsw!
On p. 2-33 of Ref. [15 e]
US DIVING MANUAL_REV7_ChangeA-6.6.18 ,
Free download @: <http://www.divetable.eu/15.pdf>

Table 2-10. Pressure Equivalents.

Atmos- pheres	Bars	10 Newton Per Square Centimeter	Pounds Per Square Inch	Columns of Mercury at 0°C		Columns of Water* at 15°C			
				Meters	Inches	Meters	Inches	Feet (FW)	Feet (FSW)
1	1.01325	1.03323	14.696	0.76	29.9212	10.337	406.966	33.9139	33.066
0.986923	1	1.01972	14.5038	0.750062	29.5299	10.2018	401.645	33.4704	32.6336
0.967841	0.980665	1	14.2234	0.735559	28.959	10.0045	393.879	32.8232	32.0026
0.068046	0.068947	0.070307	1	0.0517147	2.03601	0.703386	27.6923	2.30769	2.25
1.31579	1.33322	1.35951	19.33369	1	39.37	13.6013	535.482	44.6235	43.5079
0.0334211	0.0338639	0.0345316	0.491157	0.0254	1	0.345473	13.6013	1.13344	1.1051
0.09674	0.09798	0.099955	1.42169	0.073523	2.89458	1	39.37	3.28083	3.19881
0.002456	0.002489	0.002538	0.03609	0.001867	0.073523	0.02540	1	0.08333	0.08125
0.029487	0.029877	0.030466	0.43333	0.02241	0.882271	0.304801	12	1	0.975
0.030242	0.030643	0.031247	0.44444	0.022984	0.904884	0.312616	12.3077	1.02564	1

1. Fresh Water (FW) = 62.4 lbs/ft³; Salt Water (fsw) = 64.0 lbs/ft³.
2. The SI unit for pressure is Kilopascal (KPA)—1KG/CM² = 98.0665 KPA and by definition 1 BAR = 100.00 KPA @ 4°C.
3. In the metric system, 10 MSW is defined as 1 BAR. Note that pressure conversion from MSW to FSW is different than length conversion; i.e., 10 MSW = 32.6336 FSW and 10 M = 32.8083 feet.

[62] "Diving & Subaquatic Medicine", Carl Edmonds, Lowry, Pennefather, Walker, 4 th. Ed., Arnold, ISBN 0-340-80630-3

On p. 12: with useful ballparks, just sufficient for medical assessments. And another wise remark concerning temperature & salinity!

Pressure units

Because diving involves facets of engineering and science it is plagued with many units of pressure. These include absolute and gauge atmospheres, Pascals and multiples such as the kilopascal, feet or metres of seawater, pounds per square inch, bars and torrs, and several other rarer units. Conversions for the more commonly used units are listed in Table 2.1.

Pressure and the diver's body

Many people have difficulty in understanding why the pressure of the water does not crush the diver. The answer to this problem may be considered in two parts.

Table 2.1 *Pressure conversion factors (commonly used approximations shown in brackets)*

1 ATMOSPHERE
= 10.08 (10) metres sea water (msw)
= 33.07 (33) feet sea water
= 33.90 (34) feet fresh water
= 101.3 kilopascals (kPa) = 0.1013 mega pascals (MPa)
= 1.033 kg/cm ²
= 14.696 (14.7) lbs/in ²
= 1.013 bars
= 760 millimetres mercury (mmHg) = 760 Torr
= 1 ATA

Actual conversions from sea water depth to ATA depends on salinity and temperature.) A complete conversion matrix is provided at the end of the chapter.

[63] "Bennett and Elliott's Physiology and Medicine of Diving" Alf Brubakk, Neuman et al., 5 th Ed. Saunders, ISBN 0-7020-2571-2

In the chapter "Decompression Practice" from Bill Hamilton and Ed Thalmann we find the following clarifying hints on p. 457:

UNITS

Diving depths are expressed as units of length, meters and feet, but the concern here is really pressure, which takes the specific gravity of seawater into account. Since salt water specific gravity depends on salinity it is not the same throughout the world's oceans and therefore must be defined. *The US Navy (USN) Diving Manual* (US Dept of the Navy 1999) assigns a specific gravity of 1.02480 or a density of 64 lbs/ft³ to sea water. A depth of 1 foot of seawater (fsw) is thus defined such that 33.066 fsw equals 1 atm. This is commonly rounded off to 33.00 fsw/atm. In Europe the meter of seawater (msw) is defined such that 10 meters of seawater (10 msw) is exactly equal to a pressure of 1.0 bar (100 kPa), giving a specific gravity of seawater of 1.01972. This means that converting from msw to fsw is not simply a matter of converting meters to feet. Using 33.066 fsw/atm the conversion is 3.2633 fsw/msw, and for 33.0 fsw/atm the conversion is 3.2568 fsw/msw. In this chapter units are given in the primary unit of the source; conversions to and from SI/metric units may be approximate when the original value refers to a range or is categorical.

[63] "Bennett and Elliott's Physiology and Medicine of Diving" Alf Brubakk, Neuman et al., 5 th Ed. Saunders, ISBN 0-7020-2571-2

In the appendix on p. 760
is the following matrix
(excerpt):

fsw	msw	psi	atm
0	0	0	0
16.5	5.03	7.35	0.5
33	10.06	14.7	1
49.5	15.09	22.05	1.5
66	20.12	29.4	2
82.5	25.15	36.75	2.5
99	30.18	44.1	3
115.5	35.22	51.45	3.5
132	40.23	58.8	4
148.5	45.28	66.15	4.5

[158] Shilling, C. W. Carlston, C.B. Mathias, R.A (1984) *The Physician's Guide to Diving Medicine*, Plenum Press, N.Y., ISBN-13: 978-1-4612-9663-8, p. 36:

SUB
MARINE
CONSULTING

1. Units of Pressure

Pressure units in this field are too numerous to remember: feet or meters of salt or fresh water; inches of mercury (in. Hg); millimeters of mercury (mmHg); pounds per square inch (psi); grams or kilograms per square centimeter (g/cm^2 or kg/cm^2); bars or millibars (bar or mbar); pascal (Pa); torricelli (torr); and standard physical atmosphere (atm). The more common units are expressed at sea level as follows:

- 1 atm = 29.9 inches of mercury (in. Hg)
- = 760 millimeters of mercury (mmHg)
- = 101.3 kilopascals (kPa)
- = 33 feet of seawater (fsw)
- = 34 feet of fresh water
- = 14.7 pounds per square inch ($\text{lb}/\text{in.}^2$; psi)
- = 1033 grams per square centimeter (g/cm^2)
(seen only in the old literature)
- = 10.08 meters of seawater (msw)
- = 1013.3 millibars (mbar)

And then, on p. 50, concerning the average density of seawater (citation):
“... $1.026 \text{ g}/\text{cm}^3$ @ 15°C .”

*The next 4 slides are just screen shots from various books:
the conversion factors for the various pressure units
sometimes far out in the left field.*

The yellow display is ours:

[75], Bove and Davis' Diving Medicine,
4th. Edition, p. 575, Appendix I
(truncated)

**Multiply
This Unit →
To obtain**



kg/cm²

ata

atm

Bar

mm Hg

lb/in²

Meters seawater (msw)

Feet seawater (fsw)

Pascal (Pa)

Pascal[†] (Pa)

1.02×10^{-5}

1.02×10^{-5}

0.987×10^{-5}

1.040×10^{-5}

7.502×10^{-3}

1.45×10^{-4}

0.898×10^{-4}

3.264×10^{-4}

1.00

Appendix 1

Pressure Conversion Table

SUB
MARINE
CONSULTING

Pressure Units Found in Articles

	kg/cm ²	at*	atm†	bar
kg/cm ²	1	1.000	1.033	1.020
at*	1.000	1	1.033	1.020
atm†	9.678×10^{-1}	9.678×10^{-1}	1	9.869×10^{-1}
bar	9.807×10^{-1}	9.807×10^{-1}	1.013	1
torr				
mm Hg	735.5	735.5	760	750.1
lbs/in ²	1.422×10^1	1.422×10^1	1.470×10^1	1.450×10^1
meters sea water (msw)	1.000×10^1	1.000×10^1	1.033×10^1	1.020×10^1
feet sea water (fsw)	3.198×10^1	3.198×10^1	3.305×10^1	3.261×10^1

*Technical atmosphere, equal to 1 kg/cm².

†Standard atmosphere, equal to pressure exerted by a column of mercury 760 mm high at a temperature where the density of mercury is 13.5951 g/cm³.

Courtesy Undersea Biomedical Research, 9650 Rockville Pike, Bethesda, Maryland, 20014, 1974.

[248], Strauss, R.H.
(ed.)(1976) Diving Medicine,
Grune & Stratton, Inc., N.Y.,
ISBN 0-8089-0699-2

on p. 348:

[110] The Underwater Handbook:
A Guide to Physiology and
Performance for the Engineer;
Shilling, Werts,
Schandelmaier;
Plenum Press N.Y.,
1976, ISBN 0-306-30843-6

A very complete matrix,
with high precision, on p. 893,
but not without flaws ...
(pls. cf. next slide)

Table A-3
Units of Pressure Conversion Table

From \ To	Multiply by			
	Atm abs	ATA	Bar	dyn/cm ²
Atm abs		1.03323	1.01325	1.01325 × 10 ⁶
ATA	0.967841		0.980665	9.80665 × 10 ⁵
Bar	1.01325	0.980665		1 × 10 ⁶
dyn/cm ²	9.86923 × 10 ⁻⁷	1.01972 × 10 ⁻⁹	1 × 10 ⁻⁹	
ft sea water	0.030238	0.031243	0.0306391	3.06391 × 10 ⁴
ft pure water	0.029499	0.030480	0.0298898	2.98898 × 10 ⁴
kg-f/cm ²	0.967841	1.0	0.980665	9.80665
kg-f/m ²	9.67841 × 10 ⁻⁵	1 × 10 ⁻⁴	9.80665 × 10 ⁻⁵	98.0665
Meter sea water	0.099206	0.102503	0.100522	1.00522 × 10 ⁵
Meter pure water	0.096784	0.10	0.0980665	9.80665 × 10 ⁴
mm Hg	1.31579 × 10 ⁻³	1.35951 × 10 ⁻³	1.33323 × 10 ⁻³	1.33323 × 10 ³
Pa	9.86923 × 10 ⁻⁸	1.01972 × 10 ⁻⁵	1 × 10 ⁻⁵	10.0
PSI	0.0680457	0.0703087	0.0689474	6.89474 × 10 ⁴

From \ To	Multiply by			
	ft sea water	ft pure water	kg-f/cm ²	kg-f/m ²
Atm abs	33.071	33.8995	1.03323	1.03323 × 10 ⁴
ATA	32.007	32.808	1.00	10,000
Bar	3.2638	33.4562	1.01972	1.01972 × 10 ⁴
dyn/cm ²	3.26380 × 10 ⁻⁵	3.34562 × 10 ⁻⁵	1.01972 × 10 ⁻⁸	1.01972 × 10 ⁻²
ft sea water		1.0250	3.12427 × 10 ⁻²	312.427
ft pure water	0.975610		0.03048	304.8
kg-f/cm ²	32.007	32.808		1 × 10 ⁴
kg-f/m ²	3.2007 × 10 ⁻³	3.2808 × 10 ⁻³	1 × 10 ⁻⁴	
Meter sea water	3.28085	3.36305	0.102503	1025.03
Meter pure water	3.2007	3.2808	0.10	1000
mm Hg	4.35145 × 10 ⁻²	4.46046 × 10 ⁻²	1.35951 × 10 ⁻²	13.5951
Pa	3.26380 × 10 ⁻⁴	3.34562 × 10 ⁻⁴	1.01972	0.101972
PSI	2.25031	2.30672	7.03068 × 10 ²	703.068

From \ To	Multiply by				
	Meter sea water	Meter pure water	mm Hg	Pa	PSI
Atm abs	10.080	10.3323	760.0	1.01325 × 10 ⁵	14.6960
ATA	9.7559	10.00	735.56	9.80665 × 10 ⁴	14.223
Bar	9.94810	10.1972	750.06	1 × 10 ⁵	14.5038
dyn/cm ²	9.94810 × 10 ⁻⁶	1.01972 × 10 ⁻⁵	7.50058 × 10 ⁻⁴	0.10	1.45038 × 10 ⁻⁵
ft sea water	0.30480	0.312427	22.9809	3.06391 × 10 ³	0.444377
ft pure water	0.297350	0.3048	22.4192	2.98898 × 10 ³	0.433517
kg-f/cm ²	9.7559	10.0	735.557	9.80665 × 10 ⁴	14.223
kg-f/m ²	9.7559 × 10 ⁻⁴	1 × 10 ⁻³	0.073557	9.80665	1.4223 × 10 ⁻³
Meter sea water		1.02503	75.3968	1.00522 × 10 ⁴	1.45793
Meter pure water	0.97559		73.556	9.80665 × 10 ³	1.4223
mm Hg	1.32632 × 10 ⁻²	1.35951 × 10 ⁻²		1.33323 × 10 ⁻²	
Pa	9.94810 × 10 ⁻⁵	1.01972 × 10 ⁻⁴	7.50058 × 10 ⁻³		1.45038 × 10 ⁻⁴
PSI	0.685896	0.703068	51.7147	6.89474 × 10 ³	

(+) 1/1.01325

(*) 32,6380 → (+) konstanz

? (1.01325)⁻¹ = 0,986923

[110] p. 893:

Table A-3
Units of Pressure Conversion Table

From	To	Multiply by			
		Atm abs	ATA	Bar	dyn/cm ²
Atm abs			1.03323	1.01325	1.01325 × 10 ⁶
ATA	0.967841			0.980665	9.80665 × 10 ⁵
Bar	1.01325	0.980665			1 × 10 ⁶
dyn/cm ²	9.86923 × 10 ⁻⁷	1.01972 × 10 ⁻⁹	1 × 10 ⁻⁶		
ft sea water	0.030238	0.031243	0.0306391	(*)	3.06391 × 10 ⁴
ft pure water	0.029499	0.030480	0.0298898		2.98898 × 10 ⁴
kg-f/cm ²	0.967841	1.0	0.980665		9.80665 × 10 ⁵

From \ To	ft sea water	ft pure water
Atm abs	33.071	33.8995
ATA	32.007	32.808
Bar	(+) 3.2638	33.4562
dyn/cm ²	3.26380 × 10 ⁻⁵	3.34562 × 10 ⁻⁵
ft sea water		1.0250

kg-f/m ²	9.7559 × 10 ⁻⁴	1 × 10 ⁻³	0.073557	9.80665	1.4223 × 10 ⁻³
Meter sea water		1.02503	75.3968	1.00522 × 10 ⁴	1.45793
Meter pure water	0.97559		73.556	9.80665 × 10 ³	1.4223
mm Hg	1.32632 × 10 ⁻²	1.35951 × 10 ⁻²		1.33323 × 10 ⁻³	
Pa	9.94810 × 10 ⁻⁵	1.01972 × 10 ⁻⁴	7.50058 × 10 ⁻³		1.45038 × 10 ⁻⁴
PSI	0.685896	0.703068	51.7147	6.89474 × 10 ³	

(+) 1/x ↘
 (*) 32,6380 → (+) konsistat
 ? (1.01325)⁻¹ ≈ 0,986923

Conclusion / Advice:

If possible, use the SI system.
If not, use the ballparks from [62] on p. 12:
these are sufficient for all practical purposes:
they will match the average precision of all depth gauges, dive computers or oxygen analyzers.

For scientific accuracy needed in meticulous calculations, say in a decompression algorithm or for a deep saturation dive, check for the set of conversion factors you picked the (water-)temperature and (water-)density they are defined for!
And then:

Double Check!!!
if they fit your intended environment!

Table 2.1 Pressure conversion factors (*commonly used approximations shown in brackets*)

1 ATMOSPHERE
= 10.08 (10) metres sea water (msw)
= 33.07 (33) feet sea water
= 33.90 (34) feet fresh water
= 101.3 kilopascals (kPa) = 0.1013 mega pascals (MPa)
= 1.033 kg/cm ²
= 14.696 (14.7) lbs/in ²
= 1.013 bars
= 760 millimetres mercury (mmHg) = 760 Torr
= 1 ATA

Actual conversions from sea water depth to ATA depends on salinity and temperature.) A complete conversion matrix is provided at the end of the

References (1):

We from the lab (Miri, Nurit & Yael) rely heavily on the knowledge & experience of our boss:

<https://www.researchgate.net/profile/Albi-Salm-2>

As well we have our big library at hand:

<http://www.divetable.eu/BOOKS/index.htm>

אלבי: תודה רבה!
מירי, נורית ויעל

[15 e] US DIVING MANUAL_REV7_ChangeA-6.6.18

[62] "Diving & Subaquatic Medicine", Carl Edmonds, Lowry, Pennefather, Walker, 4 th. Ed., Arnold, ISBN 0-340-80630-3,

[63] "Bennett and Elliott's Physiology and Medicine of Diving" Alf Brubakk, Neuman et al., 5 th Ed. Saunders, ISBN 0-7020-2571-2

[75], Bove and Davis' Diving Medicine, 4th. Edition

References (2):

[110] The Underwater Handbook: A Guide to Physiology and Performance for the Engineer; Shilling, Werts, Schandelmaier; Plenum Press N.Y., 1976, ISBN 0-306-30843-6

[158] Shilling, C. W. Carlston, C.B. Mathias, R.A (1984) The Physician's Guide to Diving Medicine, Plenum Press, N.Y., ISBN-13: 978-1-4612-9663-8

[248] Strauss, R.H. (ed.)(1976) Diving Medicine, Grune & Stratton, Inc., N.Y., ISBN 0-8089-0699-2

References (3):

SUB
MARINE
CONSULTING

„The diving medical detectives-series on ResearchGate:
when diving medicine books are completely wrong!”
Parts # 1 to 4:

[1] Salm, A. (09.09.2021) DOI: : [10.13140/RG.2.2.15199.79528](https://doi.org/10.13140/RG.2.2.15199.79528)

[2] Salm, A. (17.09.2021) DOI: [10.13140/RG.2.2.35722.39366](https://doi.org/10.13140/RG.2.2.35722.39366)

[3] Salm, A. (01.12.2021) DOI: [10.13140/RG.2.2.28043.62245](https://doi.org/10.13140/RG.2.2.28043.62245)

[4] Salm, A. (06/2022) DOI: [10.13140/RG.2.2.12077.97760](https://doi.org/10.13140/RG.2.2.12077.97760)