SC/BIOL 2090.02— Current Topics in Biophysics — TERM TEST ONE

Name:__________KEY____________ Student ID:_____________________

There are <u>three</u> questions. You must complete <u>all</u> three. Ensure that you show your work (that is, equations, calculations and units). Excessive length is not encouraged.

QUESTION ONE

Many multi-cellular organisms rely on internal pumps to provide nutrients and oxygen throughout their bodies. Gravity can be a counteracting force. As one example, consider a python lying horizontal on the grass versus climbing a tree, head-up. Snake lengths vary, but the heart is usually situated 0.25 of the total length behind the head for tree climbers. For non-tree climbers the heart is situated at about 0.37 of the total length. So, for a 10-meter long tree-climbing snake, the heart is 2.5 meters behind the head. The blood pressure of a tree-climbing snake is about 10.5 kiloPascals.

Consider what happens when the snake slithers from a horizontal to a vertical orientation (head-up).

- Quantify and compare two strategies the snake could use when it starts to climb the tree: changing the *work* per heart beat (volume compression per pump cycle) or changing the heart beat *rate*. Is one strategy better than the other, or are they equivalent? Explain, showing your calculations.

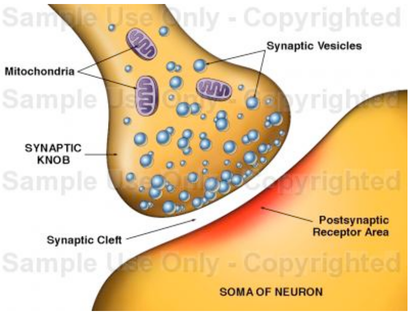
- Would it matter whether the vascular system was a closed piping system (without an opening to the outer atmosphere) or open at some location (to allow some pressure equilibration between the vascular system and the outer atmosphere)? Explain.

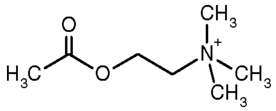
Show your work *with clarity*.

QUESTION TWO

What is R (the gas constant)? Why is it available in a bewildering array of values (see constants handout)? Remember that Dr. Lew is not a physicist, and he believes that units are important.

QUESTION THREE





Acetylcholine is a crucial neurotransmitter in your 'electrical system'. It is released at the pre-synaptic membrane, *diffuses* across the synaptic cleft and binds to acetylcholine receptor on the post-synaptic membrane, to cause the next neuron to fire electrical impulses. Assuming the diffusion coefficient is 4×10^{-6} cm^2 s^{-1}, how wide could the synapse gap be if acetylcholine must diffuse across the synaptic cleft in 10^{-5} sec?

Term Test Key

Question One (/20)

(Part One)

In a vertical position, the snake has to overcome $\rho g h$. To do so, it can either change the volume compressed per heart beat, or increase the heart rate. (3/10)

The two are related:

$$\text{Volume Flow} = \begin{pmatrix}\text{compressed} \\ \text{volume}\end{pmatrix}\begin{pmatrix}\text{heart beat} \\ \text{rate}\end{pmatrix}$$

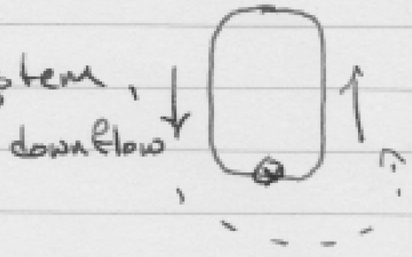
(6/10)

Increasing either will increase volume flow.

In biological reality, changing the heart chamber volume is difficult, while increasing heart beat rate is straightforward, and what a tree climbing snake will actually do (1/10)

(Part Two)

In a closed system,



will "pull" up flow (5/10)

In an open system

the two are no longer connect~~ing~~ed, so the snake must overcome atmospheric pressure, creating difficulties (5/10)

A more detailed physical exploration of tree-climbing pythons was provided to you on the course website, as a sample assignment and gives more details.

Term Test One Key

Question Two (/20)

The gas constant "glues" together thermodynamic properties:

$$PV = nRT \quad \text{or} \quad P = RTc$$

(8/20)

So, in part, the values of R depend upon the units you are using. As one example,
$m^3\,Pa\,mol^{-1}\,K^{-1}$, liter atm $mol^{-1}\,K^{-1}$, and cm^3 bar $mol^{-1}\,K^{-1}$ are all (in state properties) $V\,P\,mol^{-1}\,K^{-1}$.

(8/20)

More deeply, R can be expressed in $\frac{\text{Joules}}{\text{mol K}}$ (i.e., energy)

Are joules equivalent to $m^3\,Pa$ $(V \cdot P)$?

Since a Pa is N/m^2 ...

$$m^3\,\frac{N}{m^2} = \underbrace{N}_{\frac{kg\,m}{s^2}} \cdot m = \underbrace{\text{joule}}_{\frac{kg \cdot m^2}{s^2}}.$$

$N \cdot m$ is the work (or energy) done when applying one Newton of force through a distance of 1 m.

(4/20)

Term Test One Key (/20)

Question Three

To determine the maximal width of the synaptic cleft, we can use Einstein's relation

$$D = \frac{1}{2}\frac{\Delta^2}{\tau}$$

Solving for the distance (Δ)

$$\Delta = \sqrt{2D\tau}$$

$d = \sqrt{6Dt}$ could also be used.

$$\sqrt{(2)\left(4\times10^{-6}\,\frac{cm^2}{\cancel{sec}}\right)\left(10^{-5}\,\cancel{sec}\right)}$$

units = cm $\quad \Delta = 8.9\times10^{-6}$ cm

or 89 nm

(not very wide at all !)

A more detailed physical exploration of diffusion in an enclosed space was provided for you as a sample assignment (Diffusion assignment) on the course web site.

$$N_T = N_0 \bullet 2^{(T/g)}$$

as time increases, t/g = 1, 2, 3 ..., thus 2^1, 2^2, 2^3, etc.

g is the generation time

N_0 is the number of cells at time T = 0

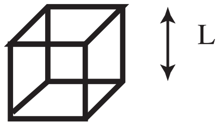
N_T is the number of cells at time T

Logistic growth curve:

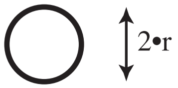
$$N_T = \frac{K \bullet N_0 \bullet e^{T/g}}{K + N_0(e^{T/g} - 1)}$$

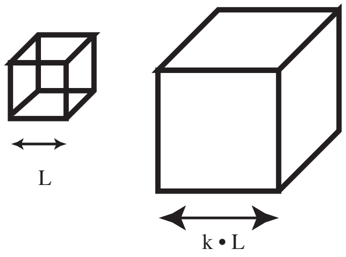
K is the carrying capacity

A cube has a surface area of $6 \bullet L^2$. Its volume is L^3. As long as the shape is constant, the ratio of suraface area to volume will always be $(6 \bullet L^2) / L^3$, or 6/L.



For a sphere, the surface area is $4 \bullet \pi \bullet r^2$, and the volume is $\pi \bullet r^3$; the corresponding ratio of surface area to volume is 4/r.





(area) $A_1 = 6 \bullet L^2$ $A_k = 6 \bullet (k \bullet L)^2$ $A_k = 6 \bullet k^2 \bullet L^2$ $(= k^2 \bullet A_1)$

(volume) $V_1 = L^3$ $V_k = (k \bullet L)^3$ $V_k = k^3 \bullet L^3$ $(= k^3 \bullet V_1)$

The scaling coefficient is different for area (k^2) and for volume (k^3).

Heat conduction rates are defined by the relation:

$$P_{cond} = Q / t = k \bullet A \bullet [(T_a - T_b) / L]$$

where P_{cond} is the rate of conduction (transferred heat, Q, divided by time, t); k is the thermal conductivity; T_a and T_b are the temperatures of the two heat reservoirs a and b; A is the area; and L is the distance. Thermal conductivities of water and air are about 0.6 and 0024 W m^{-1} K^{-1}, respectively.

Thermal radiation is defined by the relation:

$$P_{rad} = \sigma \bullet \varepsilon \bullet A \bullet T^4$$

where P_{rad} is the rate of radiation; σ is the Stefan-Boltzmann constant ($5.6703 \bullet 10^{-8}$ W m^{-2} K^{-4}; ε is the emissivity (varies from 0 to 1, where 1 is for a blackbody radiator); A is the area; and T is the temperature (in Kelvins). The *net* radiative emission or absorption will depend upon the difference in temperature:

$$P_{net} = \sigma \bullet \varepsilon \bullet A \bullet (T^4_{body} - T^4_{ambient})$$

$$\text{compression} = \rho \bullet h$$

$$h_{critical} = \frac{42.4 \bullet 10^6 (\mathrm{N} \bullet \mathrm{m}^{-2}) \bullet \dfrac{1(\mathrm{kg(f)})}{9.80665(\mathrm{N})}}{436(\mathrm{kg} \bullet \mathrm{m}^3)}$$

$$F_{cr} = \frac{E \bullet I \bullet \pi^2}{L^2_{eff}}$$

$$F_{cr} = \frac{E \bullet \dfrac{\pi \bullet r^4}{4} \bullet \pi^2}{(2 \bullet h)^2}, \text{ and } F_{cr} = \rho \bullet \pi \bullet r^2 \bullet h$$

$$\Psi_{wv} = \frac{RT}{\overline{V}_w} \ln\left(\frac{\%\ \text{relative humidity}}{100}\right) + \rho_w g h$$

velocity (meters sec^{-1})

pressure difference (Pascal = 1 kg m^{-1} sec^{-1})

tube radius

$$v = \left(\frac{\Delta p}{l}\right)\left(\frac{1}{4 \bullet \eta}\right)(R^2 - r^2)$$

distance (meters)

viscosity (water = 0.01 gm cm^{-1} sec^{-1}, or Pa sec)

distance from center of tube

$$v = \left(\frac{\Delta p}{l}\right)\left(\frac{1}{4 \bullet \eta}\right) R^2 \qquad J_v = \left(\frac{\Delta p}{1}\right)\left(\frac{\pi}{8 \bullet \eta}\right) \bullet R^4$$

density (water = 1 gm cm^{-3})

velocity (cm sec^{-1})

tube diameter (cm)

$$R_e = \frac{\rho \bullet \nu \bullet l}{\eta}$$

viscosity (water = 0.01 gm cm^{-1} sec^{-1})

$$J = -D\frac{\partial c}{\partial x}$$

Fick's First Law of Diffusion: The flux is proportional to the concentration gradient

$$\frac{\partial c}{\partial t} = -\frac{\partial J}{\partial x}$$

Fick's Second Law of Diffusion: Changes in concentration over time depend upon the flux gradient

$$J = -\frac{1}{2} \bullet \frac{\Delta^2}{\tau} \bullet \frac{dC}{dx}$$

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

$$D = \frac{1}{2} \bullet \frac{\Delta^2}{\tau}$$

$$\nabla \nu = u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}$$

velocity vector
—the notation grad ν
is sometimes used

with velocity components, u, v, and w,
in the three dimensions, x, y, and z.

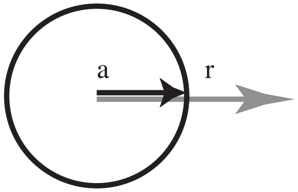
$$J_x = -D\frac{\partial c}{\partial x} + v_x \bullet c$$

units: moles cm^{-2} sec^{-1}

(cm^2 sec^{-1})(moles cm^{-4})

(cm sec^{-1})(moles cm^{-3})

$$J_V = -\frac{r^2}{8 \bullet \eta} \bullet \frac{\partial P}{\partial x}$$



Fick's First law : $J_r = -D\frac{\partial C}{\partial r}$

Fick's Second Law :
(steady state)

$$C(r) = C_0\left(1 - \frac{a}{r}\right)$$

$$\frac{\partial C}{\partial t} = D\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right) = 0$$

$$J_r(a) = -D \bullet C_0 \bullet 4 \bullet \pi \bullet a = I_D \text{ (diffusive current)}$$

(units of mole sec^{-1})

(mole cm^{-2} sec^{-1})

$$I_m = 4 \bullet \pi \bullet a^2 \bullet \beta \text{ (metabolic current)}$$

(cm^2) (units of mole sec^{-1})

$$\frac{\partial C}{\partial t} = u \bullet \frac{\partial C}{\partial r} \bullet C + D\frac{\partial^2 C}{\partial r^2}$$

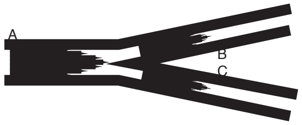
flow velocity

concentration gradient

concentration

$$P_e = \frac{2 \bullet a \bullet u}{D}$$

$$Q = \frac{\Delta p}{l}\frac{\pi a^4}{8\eta}$$



$$\mu_j^{liquid} = \mu_j^* + RT\ln a_j + \overline{V}_j P + z_j FE + m_j gh$$

fluid density

velocity

$$D = \frac{1}{2} \bullet \rho \bullet V^2 \bullet A \bullet C_D$$

frontal area

drag coefficient
(shape-dependent)

$$m\left(-\frac{d\upsilon}{dt}\right) = 6 \bullet \pi \bullet \eta \bullet \mathrm{r} \bullet \upsilon$$

$$\upsilon(\mathrm{t}) = \upsilon_0 e^{\left(-\frac{6 \bullet \pi \bullet \eta \bullet r}{m} \bullet t\right)}$$

$$p_o(t) = e^{-\lambda}$$

$$p_n = e^{-\lambda T}\frac{(\lambda T)^n}{n!} = \frac{e^{-\mu}\mu^k}{k!}$$

$$\text{Rotor}_{(n)} + mH^+_{\text{outside}} \longleftrightarrow \text{Rotor}_{(n+1)} + mH^+_{\text{inside}}$$

$$\text{ADP} + \text{P}_i + \text{mH}^+_{\text{outside}} \longleftrightarrow \text{ATP} + \text{mH}^+_{\text{inside}}$$

gas constant

Faraday constant

Voltage

$$\mu = \mu^{\circ} + RT\ln(a_{H^+}) + zF\Psi$$

temperature

activity of protons

$$\Delta G_{\text{ATP}} = \Delta G^{\circ}_{\text{ATP}} + RT\ln\left(\frac{[ATP]}{[ADP][P_i]}\right)$$

$$\Delta G_{\text{total}} = n \bullet \Delta\mu_{H^+} + \Delta G_{ATP} = 0$$

$$n \bullet \left(RT\ln\left(\frac{a^{inside}_{H^+}}{a^{outside}_{H^+}}\right) + F\Delta\Psi\right) + \Delta G^{o}_{ATP} + RT\ln\left(\frac{[ATP]}{[ADP][P_i]}\right) = 0$$

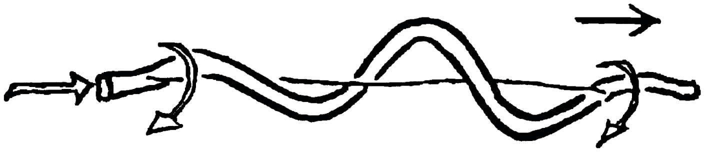
$$\Delta\mu_{H^+} = \frac{RT}{F}\ln\left(\frac{a^{inside}_{H^+}}{a^{outside}_{H^+}}\right) + \Delta\Psi \quad \text{(units: mV)}$$

RT/F is about 25 mV at 20ºC.

$$F = A\upsilon + B\omega$$

$$N = C\upsilon + D\omega$$

That is, both velocity and rotation contribute to both the force and torque.



The work exerted will depend upon the speed of the contraction, and the cross-sectional area of the muscle times its length. Muscle contraction speeds are normally in the range of 3 milliseconds. The initial velocity will equal the impulse force divided by the mass ($\nu = F_{\text{impulse}}/\text{mass}$).

The work done in the leap is proportional to mass and the height of the leap ($W \propto mH$), while the work of the muscles is proportional to the mass of the muscle (or the whole organism) ($W \propto m$). It follows then, that the total work is related solely to the height, since the organism's mass cancels out. Thus, the height of the leap is not proportional to the organisms's size, but rather is similar for any organism. D'Arcy Thompson describes this as an example of the Principle of Biological Similitude.

$$\mu^{liquid}_j = \mu^*_j + RT\ln a_j + \overline{V}_j P + z_j FE + m_j gh$$

$$RT\ln a_j + \overline{V}_j P + m_j gh$$

gravitational potential

$$a_j = \gamma_j c_j$$

The activity of water (a_j) is the product of the activity coefficient and the concentration of water

$$\overline{V}_j = \left(\frac{\partial V}{\partial n_j}\right)_{n_i,T,P,E,h}$$

The partial molal volume of species j is the incremental increase in volume with the addition of species j. For water, it is 18.0 X 10^{-6} $\text{m}^3\ \text{mol}^{-1}$.

$$RT\ln a_j = \overline{V}_j\Pi$$

osmotic pressure

$$\Pi_s = RT\sum_j c_j$$

Van't Hoff relation

The terms inter-relate various properties of water: changes in its activity with the addition of solutes, and the relation to pressure.

APPENDIX I

Numerical Values of Constants and Coefficients

Symbol	Description	Magnitude
c	speed of light in vacuum	2.998×10^8 m s^{-1}
c^*_{wv}	saturation concentration of water vapor (i.e., at 100% relative humidity)	See pp. 548–550 for values from −30°C to 60°C.
C_P^{water}	volumetric heat capacity of water at constant pressure (1 atmosphere, 0.1013 MPa)	4.217 MJ m^{-3} °C^{-1} at 0°C 4.175 MJ m^{-3} °C^{-1} at 20°C 4.146 MJ m^{-3} °C^{-1} at 40°C
C_P^{air}	volumetric heat capacity of dry air at constant pressure (1 atmosphere)	1.300 kJ m^{-3} °C^{-1} at 0°C 1.212 kJ m^{-3} °C^{-1} at 20°C 1.136 kJ m^{-3} °C^{-1} at 40°C
D_{CO_2}	diffusion coefficient of CO_2 in air (1 atmosphere, 0.1013 MPa)	1.33×10^{-5} m^2 s^{-1} at 0°C 1.42×10^{-5} m^2 s^{-1} at 10°C 1.51×10^{-5} m^2 s^{-1} at 20°C 1.60×10^{-5} m^2 s^{-1} at 30°C 1.70×10^{-5} m^2 s^{-1} at 40°C
D_{O_2}	diffusion coefficient of O_2 in air (1 atmosphere, 0.1013 MPa)	1.95×10^{-5} m^2 s^{-1} at 20°C
D_{wv}	diffusion coefficient of water vapor in air (1 atmosphere, 0.1013 MPa)	2.13×10^{-5} m^2 s^{-1} at 0°C 2.27×10^{-5} m^2 s^{-1} at 10°C 2.42×10^{-5} m^2 s^{-1} at 20°C 2.57×10^{-5} m^2 s^{-1} at 30°C 2.72×10^{-5} m^2 s^{-1} at 40°C
e	base for natural logarithm	2.71828 ($1/e$ = 0.368)
	electronic charge	1.602×10^{-19} C
F	Faraday's constant	9.649×10^4 coulomb mol^{-1} 9.649×10^4 J mol^{-1} V^{-1} 2.306×10^4 cal mol^{-1} V^{-1} 23.06 kcal mol^{-1} V^{-1}

Symbol	Description	Magnitude
g	gravitational acceleration	9.780 m s^{-2} (sea level[1], 0° latitude) 9.807 m s^{-2} (sea level[1], 45° latitude) 9.832 m s^{-2} (sea level[1], 90° latitude) 978.0 cm s^{-2} (sea level[1], 0° latitude) 980.7 cm s^{-2} (sea level[1], 45° latitude) 983.2 cm s^{-2} (sea level[1], 90° latitude)
h	Planck's constant	6.626×10^{-34} J s 6.626×10^{-27} erg s 0.4136×10^{-14} eV s 1.584×10^{-37} kcal s
hc		1.986×10^{-25} J m 1 240 eV nm
H_{sub}	heat of sublimation of water	51.37 kJ mol^{-1} (2.847 MJ kg^{-1}) at −10°C 51.17 kJ mol^{-1} (2.835 MJ kg^{-1}) at −5°C 51.00 kJ mol^{-1} (2.826 MJ kg^{-1}) at 0°C 12.27 kcal mol^{-1} (680 cal g^{-1}) at −10°C 12.22 kcal mol^{-1} (677 cal g^{-1}) at −5°C 12.18 kcal mol^{-1} (675 cal g^{-1}) at 0°C
H_{vap}	heat of vaporization of water	45.06 kJ mol^{-1} (2.501 MJ kg^{-1}) at 0°C 44.63 kJ mol^{-1} (2.477 MJ kg^{-1}) at 10°C 44.21 kJ mol^{-1} (2.454 MJ kg^{-1}) at 20°C 44.00 kJ mol^{-1} (2.442 MJ kg^{-1}) at 25°C 43.78 kJ mol^{-1} (2.430 MJ kg^{-1}) at 30°C 43.35 kJ mol^{-1} (2.406 MJ kg^{-1}) at 40°C 42.91 kJ mol^{-1} (2.382 MJ kg^{-1}) at 50°C 40.68 kJ mol^{-1} (2.258 MJ kg^{-1}) at 100°C
k	Boltzmann's constant	1.381×10^{-23} J molecule^{-1} K^{-1} 1.381×10^{-16} erg molecule^{-1} K^{-1} 8.617×10^{-5} eV molecule^{-1} K^{-1}
kT		0.02354 eV molecule^{-1} at 0°C 0.02526 eV molecule^{-1} at 20°C 0.02569 eV molecule^{-1} at 25°C 0.02699 eV molecule^{-1} at 40°C
K^{air}	thermal conductivity coefficient of dry air (1 atmosphere)[2]	0.0237 W m^{-1} °C^{-1} at −10°C 0.0243 W m^{-1} °C^{-1} at 0°C 0.0250 W m^{-1} °C^{-1} at 10°C 0.0257 W m^{-1} °C^{-1} at 20°C 0.0264 W m^{-1} °C^{-1} at 30°C 0.0270 W m^{-1} °C^{-1} at 40°C 0.0277 W m^{-1} °C^{-1} at 50°C

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1. The correction for height above sea level is -3.09×10^{-6} m s^{-2} per m of altitude.

2. The pressure sensitivity is very slight, K^{air} increasing only about 0.0001 W m^{-1} °C^{-1} per atmosphere (0.1013 MPa) increase in pressure.

Symbol	Description	Magnitude
	thermal conductivity coefficient of moist air (100% relative humidity, 1 atmosphere)	0.0242 W m^{-1} °C^{-1} at 0°C 0.0255 W m^{-1} °C^{-1} at 20°C 0.0264 W m^{-1} °C^{-1} at 40°C
K^{water}	thermal conductivity coefficient of water	0.565 W m^{-1} °C^{-1} at 0°C 0.599 W m^{-1} °C^{-1} at 20°C 0.627 W m^{-1} °C^{-1} at 40°C
ln 2		0.6931
N	Avogadro's number	6.0220 × 10^{23} entities mol^{-1}
Nhc		0.1196 J mol^{-1} m 119 600 kJ mol^{-1} nm 28.60 kcal mol^{-1} μm 28 600 kcal mol^{-1} nm
N^*_{wv}	saturation mole fraction of water vapor (i.e., at 100% relative humidity) at 1 atmosphere (0.1013 MPa)	See pp. 548–550 for values from −30°C to 60°C.
P^*_{wv}	saturation vapor pressure of water	See pp. 548–500 for values from −30°C to 60°C.
	protonic charge	1.602 × 10^{-19} C
R	gas constant	8.314 J mol^{-1} K^{-1} 1.987 cal mol^{-1} K^{-1} 8.314 m^3 Pa mol^{-1} K^{-1} 8.314 × 10^{-6} m^3 MPa mol^{-1} K^{-1} 0.08205 litre atmosphere mol^{-1} K^{-1} 0.08314 litre bar mol^{-1} K^{-1} 83.14 cm^3 bar mol^{-1} K^{-1}
RT		2.271 × 10^3 J mol^{-1} (m^3 Pa mol^{-1}) at 0°C 2.437 × 10^3 J mol^{-1} (m^3 Pa mol^{-1}) at 20°C 2.479 × 10^3 J mol^{-1} (m^3 Pa mol^{-1}) at 25°C 2.271 × 10^{-3} m^3 MPa mol^{-1} at 0°C 2.437 × 10^{-3} m^3 MPa mol^{-1} at 20°C 2.479 × 10^{-3} m^3 MPa mol^{-1} at 25°C 542.4 cal mol^{-1} at 0°C 582.2 cal mol^{-1} at 20°C 2.271 litre MPa mol^{-1} at 0°C 2.437 litre MPa mol^{-1} at 20°C 22.71 litre bar mol^{-1} at 0°C 24.37 litre bar mol^{-1} at 20°C 22 710 cm^3 bar mol^{-1} at 0°C 24 370 cm^3 bar mol^{-1} at 20°C 22.41 litre atmosphere mol^{-1} at 0°C 24.05 litre atmosphere mol^{-1} at 20°C
2.303 RT		5.612 kJ mol^{-1} at 20°C 5.708 kJ mol^{-1} at 25°C 1.342 kcal mol^{-1} at 20°C 1.364 kcal mol^{-1} at 25°C 56 120 cm^3 bar mol^{-1} at 20°C

Symbol	Description	Magnitude
RT/F		25.3 mV at 20°C
		25.7 mV at 25 °C
$2.303\ RT/F$		58.2 mV at 20°C
		59.2 mV at 25°C
		60.2 mV at 30°C
$RT/\overline{V}_w$		135.0 MPa at 20°C
		137.3 MPa at 25°C
		32.31 cal cm^{-3} at 20°C
		135.0 J cm^{-3} at 20°C
		1 350 bars at 20°C
		1 330 atmospheres at 20°C
$2.303\ RT/\overline{V}_w$		310.9 MPa at 20°C
		316.2 MPa at 25°C
		3 063 atmospheres at 20°C
		3 109 bars at 20 °C
	solar constant	1 368 W m^{-2}
		1.960 cal cm^{-2} min^{-1}
		1.368×10^5 erg cm^{-2} s^{-1}
		0.1368 W cm^{-2}
	thermal capacity of water (mass basis)	4 218 J kg^{-1} °C^{-1} at 0°C
		4 182 J kg^{-1} °C^{-1} at 20°C
		4 179 J kg^{-1} °C^{-1} at 40°C
		1.0074 cal g^{-1} °C^{-1} at 0°C
		0.9988 cal g^{-1} °C^{-1} at 20°C
		0.9980 cal g^{-1} °C^{-1} at 40°C
	thermal capacity of water (mole basis)	75.99 J mol^{-1} °C^{-1} at 0°C
		75.34 J mol^{-1} °C^{-1} at 20°C
		75.28 J mol^{-1} °C^{-1} at 40°C
		18.14 cal mol^{-1} °C^{-1} at 0°C
		17.99 cal mol^{-1} °C^{-1} at 20°C
		17.98 cal mol^{-1} °C^{-1} at 40°C
$\overline{V}_w$	partial molal volume of water	1.805×10^{-5} m^3 mol^{-1} at 20°C
		18.05 cm^3 mol^{-1} at 20°C
ε_0	permittivity of a vacuum	8.854×10^{-12} coulomb^2 m^{-2} N^{-1}
		8.854×10^{-12} coulomb m^{-1} V^{-1}
η_{air}	viscosity of air	1.716×10^{-5} Pa s at 0°C
		1.813×10^{-5} Pa s at 20°C
		1.907×10^{-5} Pa s at 40°C
η_w	viscosity of water	1.787×10^{-3} Pa s at 0°C
		1.307×10^{-3} Pa s at 10°C
		1.002×10^{-3} Pa s at 20°C
		0.798×10^{-3} Pa s at 30°C
		0.653×10^{-3} Pa s at 40°C
		0.547×10^{-3} Pa s at 50°C
		0.01002 dyn s cm^{-2} at 20°C
		0.01002 poise at 20°C

Symbol	Description	Magnitude
ν_{air}	kinematic viscosity of air (dry, 1 atmosphere)	1.327×10^{-5} m^2 s^{-1} at 0°C 1.505×10^{-5} m^2 s^{-1} at 20°C 1.691×10^{-5} m^2 s^{-1} at 40°C
ν_w	kinematic viscosity of water	1.787×10^{-6} m^2 s^{-1} at 0°C 1.004×10^{-6} m^2 s^{-1} at 20°C 0.658×10^{-6} m^2 s^{-1} at 40°C
π	circumference/diameter of circle	3.14159
ρ_{air}	density of dry air (1 atmosphere, 0.1013 MPa)	1.293 kg m^{-3} at 0°C 1.205 kg m^{-3} at 20°C 1.128 kg m^{-3} at 40°C
	density of saturated air (1 atmosphere)[3]	1.290 kg m^{-3} at 0°C 1.194 kg m^{-3} at 20°C 1.097 kg m^{-3} at 40°C
ρ_w	density of water	999.8 kg m^{-3} (0.9998 g cm^{-3}) at 0°C 1 000.0 kg m^{-3} (1.0000 g cm^{-3}) at 4°C 999.7 kg m^{-3} (0.9997 g cm^{-3}) at 10°C 998.2 kg m^{-3} (0.9982 g cm^{-3}) at 20°C 995.6 kg m^{-3} (0.9956 g cm^{-3}) at 30°C 992.2 kg m^{-3} (0.9922 g cm^{-3}) at 40°C
$\rho_w g$		0.00979 MPa m^{-1} (20°C, sea level, 45° latitude) 0.0979 bar m^{-1} (20°C, sea level, 45° latitude) 979 dyn cm^{-3} (20°C, sea level, 45° latitude) 0.0966 atmosphere m^{-1} (20°C, sea level, 45° latitude)
σ	Stefan–Boltzmann constant	5.670×10^{-8} W m^{-2} K^{-4} 5.670×10^{-12} W cm^{-2} K^{-4} 8.130×10^{-11} cal cm^{-2} min^{-1} K^{-4} 5.670×10^{-5} erg cm^{-2} s^{-1} K^{-4}
σ_w	surface tension of water	0.0756 N m^{-1} (Pa m) at 0°C 0.0742 N m^{-1} (Pa m) at 10°C 0.0728 N m^{-1} (Pa m) at 20°C 0.0712 N m^{-1} (Pa m) at 30°C 0.0696 N m^{-1} (Pa m) at 40°C 7.28×10^{-8} MPa m at 20°C 72.8 dyn cm^{-1} at 20°C 7.18×10^{-5} atmosphere cm at 20°C 7.28×10^{-5} bar cm at 20°C

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[3] Moist air is less dense than dry air at the same temperature and pressure, because the molecular weight of water (18.0) is less than the average for air (29.0).