

When is 863 actually 863?

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In order to adequately understand the behavior of a physiological system it is important to characterize both its control and regulatory features. By control is meant the change in the magnitude of a particular variable, in response to a physiological stressor, that operates to establish the relative stability of another (i.e. the regulated variable) to some degree of adequacy. A typical example would be the change in alveolar ventilation (\dot{V}_A , the controlled variable), or its functional counterpart the minute ventilation (\dot{V}_E) which stabilizes the level of arterial PCO_2 (PaCO_2 , the regulated variable) at, or close to, its set point value in response to the increased pulmonary CO_2 output (\dot{V}_{CO_2}) demands of muscular exercise of moderate intensity, i.e.:

$$\dot{V}_A = 863 \cdot \dot{V}_{\text{CO}_2} / \text{PaCO}_2 \text{ ----- (Eqn 1)}$$

or

$$\dot{V}_E = 863 \cdot \dot{V}_{\text{CO}_2} / \text{PaCO}_2 (1 - V_D/V_T) \text{ ----- (Eqn 2)}$$

But some, perhaps, might wonder about the number 863 in equations 1 and 2: what is its exact role in the relationship; why 863; and is it always 863?

The number is, simply, the mass balance converter that allows the variables in the equations to be expressed in their conventional units: with \dot{V}_{CO_2} reported in liters (or milliliters) per minute under “*standard*” conditions; with \dot{V}_A reported in liters (or

milliliters) per minute under “*body*” conditions; and with PaCO₂ reported in mmHg (or torr).

Consider, firstly, the fractional concentration of alveolar CO₂ (F_ACO₂). This is simply the ratio of the pulmonary CO₂ exchange rate to the alveolar ventilation rate – each being considered *under the same physical conditions*. This has, by convention, been established as standard temperature (0°C) and pressure (one atmosphere) dry i.e. STPD

$$F_{A}CO_{2} = \dot{V}_{CO_{2}}(STPD) / \dot{V}_{A}(STPD) \text{ ----- (Eqn 3)}$$

In contrast, however, convention has reasonably dictated that the ventilatory volumes ought to be expressed under the conditions at which they actually operate (i.e. body temperature and pressure, saturated with water vapor (BTPS).

And finally the partial pressure of the gas is commonly of more interest physiologically than its fractional concentration.

Firstly, consider the relevant gas laws. Boyle’s Law stipulates that, for a given number of gas molecules (n), the pressure (P) and volume (V) are inversely related - at constant temperature (T) whereas the Charles – Gay Lussac Law stipulates that at constant V the P is directly related to T. These relationships can be combined into what is termed the “ideal” gas law*:

$$PV=nRT \text{ ----- (Eqn 4)}$$

where R is simply the “gas constant” that makes the combination of units coherent i.e. liter-atmosphere per mole-degree (°Kelvin). And so, as $PV/T = a \text{ constant (i.e. } nR)$, then

$$P_s V_s / T_s = P_b V_b / T_b \text{ ----- (Eqn 5)}$$

or by rearrangement

$$V_b = V_s * [(P_s/P_b)*(T_b/T_s)] \text{ ----- (Eqn 6)}$$

– where “s” refers to standard temperature and pressure dry and “b” to body temperature and pressure, saturated with water vapor.

And so to change the \dot{V}_{CO_2} (STPD) value to \dot{V}_{CO_2} (BTPS) to cohere with the ventilatory determination:

Step 1) apply the temperature correction (e.g. at 37°C): $310/273 = 1.14$

Step 2) then apply the pressure correction (e.g. with a water vapor pressure of 47 mmHg at 37°C): $760/713 = 1.07$

Step 3) the product: $1.14 * 1.07 = 1.21$

Step 4) then bring $F_A CO_2$ to $P_A CO_2$: i.e. multiplying by 760-47, that is 713

Step 5) $1.21 * 713 = \underline{\underline{863}}$ – “the number”!

Note, however, that in steps 2 and 4 we sequentially divided then multiplied by $P_b - 47^{**}$: Therefore, at 37°C the correction factor is 863 at all altitudes.

But if the body temperature increases as a result of the increase in metabolic rate then the number *will* change: but, by how much and to what material

consequence? Consider body temperature changes of 1, 2 and 3°C as examples (noting, however, that the temperature change resulting from a typical clinical incremental test of 10-12 mins duration is more likely to be 1°C or so).

Body Temperature (°C):	37	38	39	40
“STPD–BTPS–Torr” Conversion	863	866	869	872
% Error – assuming 863	0	0.4	0.7	1.1

At a real minute ventilation of 50 L/min, therefore, the use of 863 in equations 1 and 2 would lead to an underestimation error of approximately 0.2, 0.35 and 0.5 L/min at body temperatures of 38, 39 and 40°C respectively; for $\dot{V}O_2$ and $\dot{V}CO_2$ at a notional 2 L/min the equivalent error would be 8, 14 and 22 ml/min. This is at, or beyond, the limit of resolution of current sensors.

To be meticulous, therefore, the number 863 should be restricted to a body temperature of 37°C; but its use at other temperatures in this range (e.g. during “standard” incremental clinical exercise testing, for example) will lead to no significant detriment to interpretation.

* To be rigorous on this matter, as the actual mass of the gas molecules is space occupying and there is interaction between the gas molecules (and with the surface of the container) “real” gases do not quite follow the Boyle’s law relationship over a wide range of pressures and volumes. Van der Waal’s meticulous relationship (for one mole of the gas) accounts for this:

$$(P + a/V^2)(V - b) = RT \text{ ----- Eqn 7 (“a” and “b” being constants).}$$

But in reality the difference from the “ideal” gas law relationship is so trivially small at, or around, one atmosphere that it can be disregarded. The interested reader can find more information on these relationships in the “The Physics of Gases” by E. P. Radford Jr. in the American Physiological Society’s “Handbook of Physiology, (Section 3 (Respiration))”, 1964 pp 125-152.

** The reader may, properly, be concerned about the appropriateness of using a value of 47 mmHg for the water vapor pressure as barometric pressure and/or body temperature changes. The former is not an issue as the saturated water vapor pressure at 37°C is 47 mmHg at all altitudes. However, the value does increase as body temperature increases (the kinetic energy of gases increase as a function of increased temperature) – by approximately 2.5 mmHg for each 1°C increase in temperature. But, as discussed above for Pb, whatever value is used for the water vapor pressure (in steps 2 and 4) its influence “disappears” as a result of the sequential division-multiplication steps.