Quality assurance of Modular Metabolic Systems

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Background (1987)

Danny Rutar: (technologist, scientist)

Biophysics & Instrumentation, Melbourne.

Biomedical Engineering, Queen Vic. Hospital, Mel.

Bionic Ear Institute, Melbourne. (support R&D)

Australian Institute of Sport, Canberra. (support)

Victoria University, Human Perf. Lab., Melbourne.

Irish, Inst. of Sp., University of Limerick, Ireland.

Redback Biotek, Ireland. (Solutions Provider)

Topics

- Instrumentation Errors 101
- Sources of error - metabolic systems
- Calibration Gas errors
- Oxygen Sensor errors
- Ventilation sensor errors
- Nafion Tubing
- Breath by Breath
- Metabolic calibrator
- Metabolic System comparisons

What is your system's error for VO2?

- Do you know what your metabolic system error is ???(Value - hands up).
- How has this been measured?
- Sensor error different to system error.
- Why dont we know?
- How can we make scientific claims?

Calculating errors

simple error calculations: (instrumentation 101)

$$R = \frac{X \cdot Y}{Z}$$

$$\frac{\delta R}{|R|} \approx \frac{\delta X}{|X|} + \frac{\delta Y}{|Y|} + \frac{\delta Z}{|Z|}$$

$$\delta R = |R| \cdot \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2}$$

- 100cm rule with 1cm graduations.
- Error = +/- 0.5cm
- measure 350cm?
- Accumulated error
- = 0.5 + 0.5 + 0.5 + 0.5 = 2.0cm
- Therefore 350.0 +/- 2.0cm
- Still add errors when subtracting

$$R = X + Y - Z$$

$$\delta R \approx \delta X + \delta Y + \delta Z$$

$$\delta R = \sqrt{(\delta X)^2 + (\delta Y)^2 + (\delta Z)^2}$$

Apply errors to the VO2 equation

1. Look at the equations needed to calculate VO2.
2. Use the sensor errors for each parameter.
3. Calculate the total mathematical error as per:

$$R = X + Y - Z$$

$$\delta R \approx \delta X + \delta Y + \delta Z$$

$$\delta R = \sqrt{(\delta X)^2 + (\delta Y)^2 + (\delta Z)^2}$$

$$R = \frac{X \cdot Y}{Z}$$

$$\frac{\delta R}{|R|} \approx \frac{\delta X}{|X|} + \frac{\delta Y}{|Y|} + \frac{\delta Z}{|Z|}$$

$$\delta R = |R| \cdot \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2}$$

Average Sensor errors for VO2
(in order of importance to equation)

Oxygen	0.01-0.1%
Ventilation	1-2%
Pressure	0.05%
Carbon Dioxide	0.02%
Temperature	0.1-0.01%
Humidity	1-2%

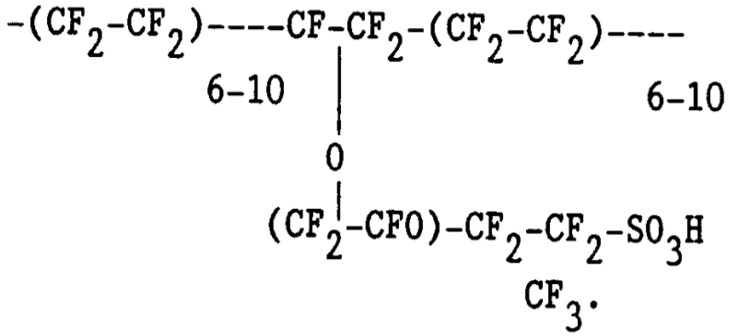
Sources of error

- O2 sensor errors
- Water vapour (humidity)
- Ventilation sensor errors
- Timing delays (Breath by Breath, also Mixing chamber)
- Gas sample bore compromise (Breath by breath)
- Breathing valves (resistance)?
- CO2 sensor errors
- Calibration gas errors (Beta/Gama gases)
- Douglas bag leaks, non Brownian motion errors.
- Temperature and pressure errors

Nafion tubing

(Jeff Swen)

- Nafion contains sulphuric acid (Teflon + Sulphuric acid)
- Nafion absorbs 22% by weight of water
- Absorbs 13 molecules H_2O for every sulfonic acid group
- Cant absorb more humidity than external tubing
- Some use freezer (peltier device) to create 0% humidity
- Sulphuric acid can corrupt gas samples - investigation.
- Oxygen and Nitrogen also pass but lower %.
- Issues with long tests (Sulphuric acid saturated)



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What parameters actually matter?

Christopher J. Gore, Rebecca K. Tanner, Kate L. Fuller and Tom Stanef (Australian Institute of Sport)

Likely error	**% VO2**
+1% FeO2	-6.46
+5% Ve	+5.00
+1% P barr	+1.01
+1% FeCo2	-0.23
+1% Temperature	-0.07
+1% RH / pH2O	-0.02
decrease gas fraction, 30% water vapour	+5.54

Reference values:

VO2 = 4.5495

VI STPD =136.10

VE STPD = 136.70

FIO2 = 0.1751%

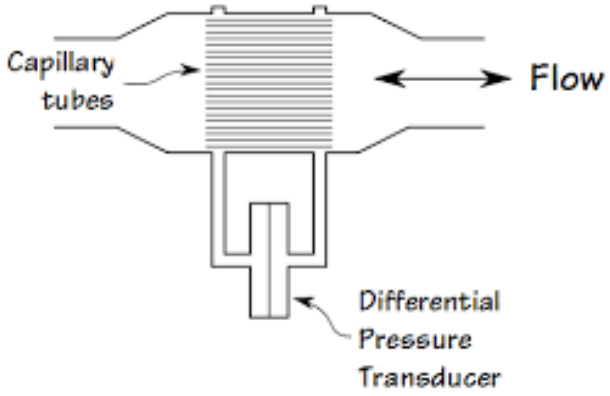
O2 = 0.2093%

Ventilometer

Pneumotach

Douglas Bag
Tissot tank

Turbine



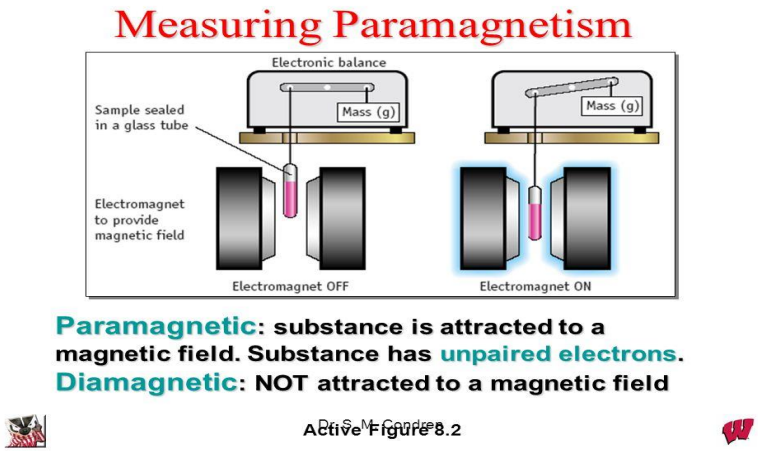
1-2%

<1%

1-3%

O2 Sensors (most critical sensor!)

Zirconia
Paramagnetic
Galvanic
others (not used)



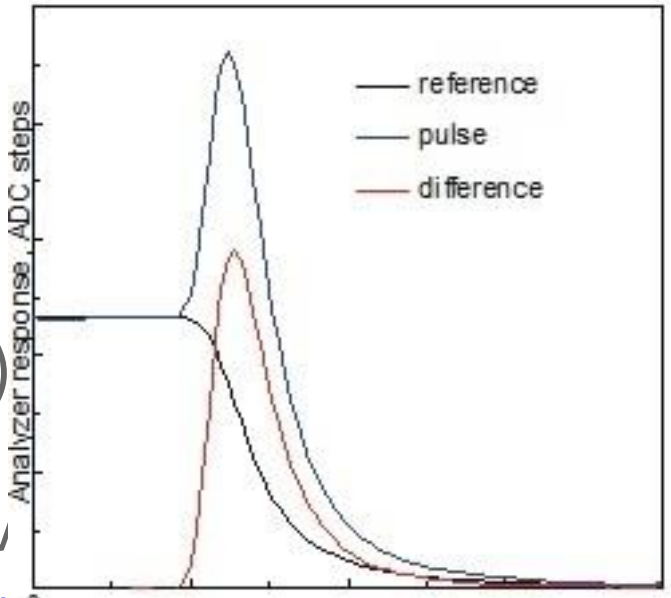
Zirconia

- **zirconia ceramic is a solid electrolyte.**
- **conductive only to oxygen ions at 700+DegC.**
- **zirconia element with a porous platinum electrode**

Photosynthesis Experiment (O2)

- Leaf experiment (Bjorkman and Gauhl, 1970).

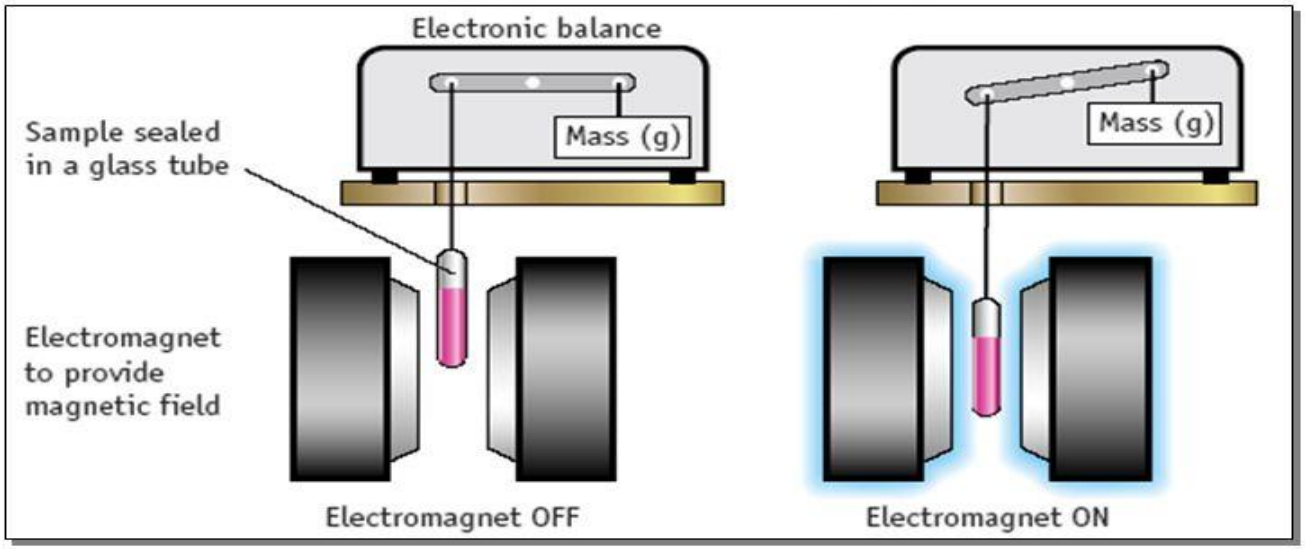
Concurrent Measurements of Oxygen and Carbon Dioxide Exchange during light pulses in a single leaf.



- M ts ev de.
  - unflower leaves)
  -]ohn P. Krall, 1993 (Maize plant)
  - Agu Laisk, 2015 (cell cultrures in v
- All stated only sensor able to measure this is Zirconia Oxide.

Paramagnetic O2 sensors

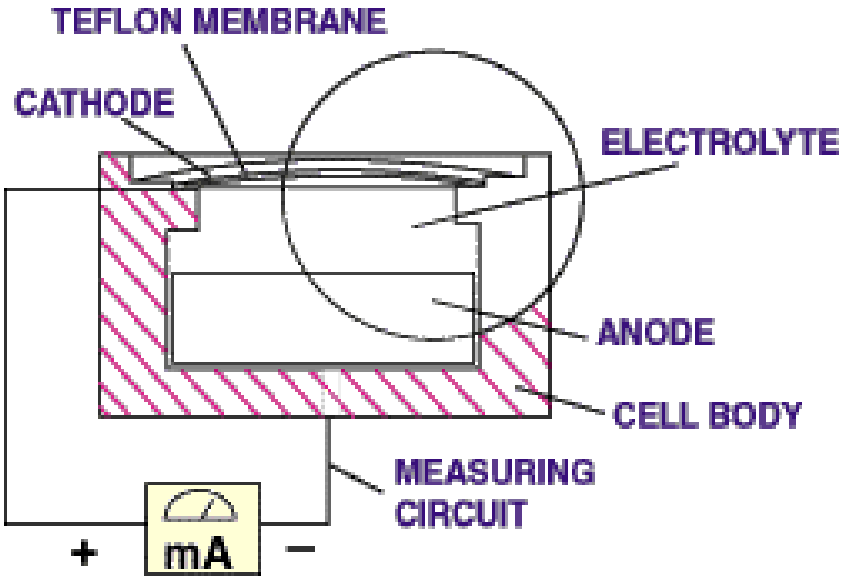
Measuring Paramagnetism



Paramagnetic: substance is attracted to a magnetic field. Substance has unpaired electrons.
Diamagnetic: NOT attracted to a magnetic field

Active Figure 8.2

Galvanic Cell O2 sensors



- Jelly electrolyte applied to gold cathode & silver anode
- Teflon membrane that is only permeable to oxygen.

Galvanic Cell O2 sensors

- **Sensor cell limited**

  (in contact with air even when not used)

  so periodic replacement is required.
- **High drift occurs if operated continuously**
- **not suitable for continuous measurements**
- **Compact & low cost**

System type comparison

- Douglas Bag: non automated (not covered)
  - Breath by Breath
- Mixing chamber
- AIS Automated

Douglas bag

best system

(0.8% error, 2% reliability)

Breath by Breath

- Easier on subject (small sample line)
- Potential for VO2 kinematics (individualised - NOT done!)
- However misalignment of VE and Fe critical! (instantaneously multiplied - large errors)
- Signal very noisy and needs averaging
- Averaging devalues the system.
- Subject to more errors than Douglas Bag or Mixing Chamber

Breath by Breath issues continued

A. Gas concentration vs flow time delay items:

1. Tubing is crimped (undetectable)
2. Tubing length changed (less likely)
3. Gas sampling rate changed (less likely)
4. Water vapour in lumen (decrease sample line)
5. Calibration procedures should allow for regular re-alignment. It doesn't / Users dont know how.

Breath by Breath issues continued

- Large data variability - one breath to the next
- Complex averaging algorithms and timing corrections - making validation difficult
- Less consistent data when compared to Mixing Chamber systems
- All points validated in papers:
  Gore et. al
  Beck et. al.
  Proctor et. al.,etc.

Mixing chamber systems
(Mr. Phil Loeb, AEI)

- **Mixing Chamber advantages**
- Every breath is recorded
- O2 and CO2 data is accurately synchronized to each breath
- Very consistent data from one breath to the next
- VO2 and VCO2 calculations utilize simple textbook formulas
- Accurate VO2 and VCO2 data as validated by Douglas Bags and 'First Principles' Simulators

Mixing Chamber systems
(Mr. Phil Loeb, AEI)

Mixing Chamber disadvantages

- A thicker sampling hose
- etO2 and etCO2 measurements need additional analyzers

A.I.S metabolic cart

(Mr. Jamie Plowman - A.I.S.)

The best of all worlds

"Automated Douglas Bags"

1. Best O2 sensor
2. Best Ve sensor
3. Automated
4. Average error 0.8%
5. Re-test human 2%
6. Fine tune with calibrator

Vacumed calibrator issues
(H.E.S.T.A.)

- **Ventilation rate too low**
- athletes need up to 7L of VO2

- **Need (heated) wet gases**

- fully mimic human breathing
- water vapout can be a significan issue
- system should test drying system and gas dilution issues

AIS Max II

(Jamie Plowman - A.I.S.)

Generates:

- gas fractions ± 0.05% absolute
  (both O_2 and CO_2)
- ventilation ±3%.
- range of physiological expirates

Interrogates any O2 system:

- accuracy of component
  O2 and CO2 analysers
- ventilation device
- software used for data reduction.

Not available commercially

DR -Quality Control Rating (1-10)

Instrument	accurate	linear	stable	reliable	Function
Zirconia	10	9.5	10	9.5	10
Paramagnetic	8	8	7	8	9
Galvanic	7	7	6	6	7
Douglas bag	10	10	10	9	4
Turbine	6-9	6-9	6-9	6-9	9
Pneumotach	7-9	7-9	8-9	8-9	9
Mixing chamber	8	9	9	9	9
Breath by Breath	7	7	7	7	9.5
AIS system	10	9.5	10	9.5	9