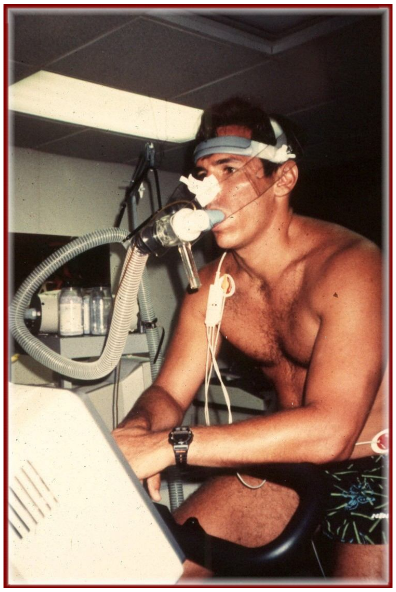
Indirect Calorimetry



CALORIMETRY

The science that quantifies the heat release from metabolism is termed **calorimetry**.

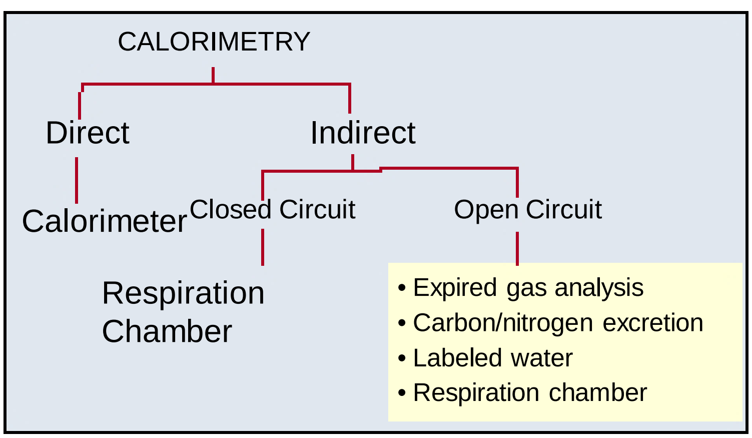
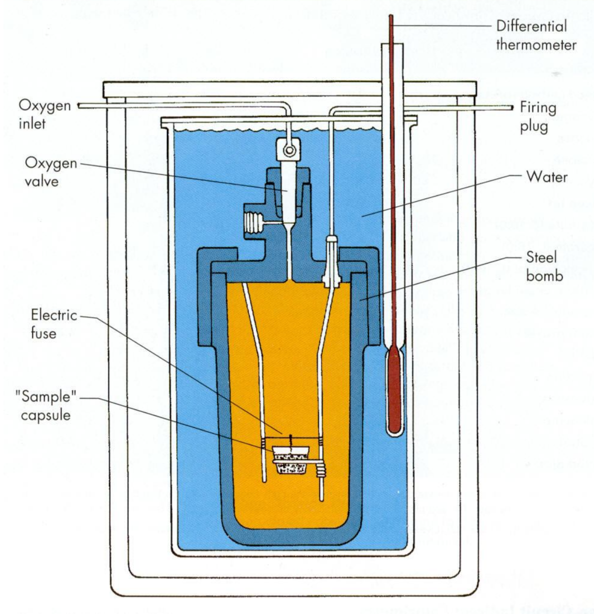
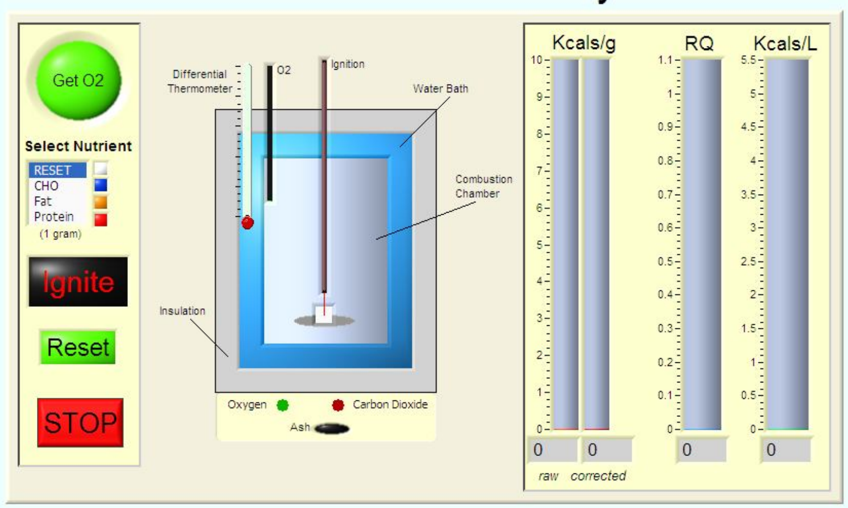


Figure 4.5

Bomb Calorimeter



Bomb Calorimetry



Heat release & caloric equivalents macronutrients

Nutrient Compound	Bomb Cal Kcals/gram	Body* Kcals/gram	RQ	Kcals/L VO_2
Carbohydrate				
Mixed	**4.1**	**4.0**	**1.0**	**5.05**
Glycogen	4.2		1.0	5.05
Glucose	3.7		1.0	4.98
Fructose	3.7		1.0	5.00
Glycerol	4.3		0.86	5.06
Fat				
Mixed	**9.3**	**9.0**	**0.7**	**4.73**
Palmitate (C16:0)	9.3		0.7	4.65
Stearate	9.5		0.69	4.65
Triacylglycerol (C18:0)	9.6		0.7	4.67
Triacylglycerol (C10-15:0)	8.4		0.74	4.69
Protein				
Mixed	**5.7**	**4.0**	**0.81**	**4.46**
Alanine	4.4		0.83	4.62
Aspartate	2.69		1.17	4.60
Glutamate	3.58		1.0	4.58
Isoleucine	6.89		0.73	4.64
Alcohol	**7.1**	**7.0**	**0.82**	**4.86**
Mixed Diet			0.84	4.83

* after Atwater correction factors (see text)

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The heat release and caloric equivalents for oxygen for the main macronutrients of catabolism (*simplified*).

Food	Rubner's kcal/g	Kcal/g (Bomb cal.)	Kcal/g (body)	RQ	Kcal/L O_2
CHO mix	4.1	4.1	4.0	1.0	5.05
Fat mix	9.3	9.3	8.9	0.70	4.73
Protein mix	4.1	5.7	4.3	0.81	4.46
Alcohol		7.1	7.0	0.82	4.86
Mixed Diet				0.84	4.83

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Applications of Indirect Calorimetry

- Maximal Cardiorespiratory and Muscular Endurance *(VO_2max)*
- Metabolic Intensity

  Absolute - VO_2 (mL/kg/min or L/min)

  Relative - % VO_2max ; % LT
- Economy and Efficiency
- Accumulated O_2 Deficit
- Metabolic Rate *(BMR, RMR)*
- EPOC
- Energy Expenditure
- VO_2 Kinetics

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Limitations Of Indirect Calorimetry

1. Whole body - the sum of all active tissue in body, not just contracting skeletal muscle.
2. Needs sophisticated and expensive equipment.
3. Highly sensitive to measurement error.
4. Can only be accurately used for metabolic intensities, economy, efficiency, and energy expenditure *during steady state exercise*.
5. Requires subjects to wear apparatus on face or in mouth.

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Systems of Measurement

Inspired volume time-average system

Expired volume time-average system

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Custom Built System

Flow turbine

Mixing bag

Flow pump

Expired gas analyzers

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Non-Protein RER Table

RQ	kcal/L O_2	% CHO*	kcal/L O_2 CHO	% FAT	kcal/L O_2 FAT
1.00	5.047	100.00	5.047	0.0	0.000
0.99	5.035	96.80	4.874	3.18	0.160
0.98	5.022	93.60	4.701	6.37	0.230
0.97	5.010	90.40	4.529	9.58	0.480
0.96	4.998	87.20	4.358	12.80	0.640
0.95	4.985	84.00	4.187	16.00	0.798
0.94	4.973	80.70	4.013	19.30	0.960
0.93	4.961	77.40	3.840	22.60	1.121
0.92	4.948	74.10	3.666	25.90	1.281
0.91	4.936	70.80	3.495	29.20	1.441
0.90	4.924	67.50	3.324	32.50	1.600
0.89	4.911	64.20	3.153	35.80	1.758
0.88	4.899	60.80	2.979	39.20	1.920
0.87	4.887	57.50	2.810	42.50	2.077
0.86	4.875	54.10	2.637	45.90	2.238
0.85	4.862	50.70	2.465	49.30	2.397
0.84	4.850	47.20	2.289	52.80	2.561
0.83	4.838	43.80	2.119	56.20	2.719
0.82	4.825	40.30	1.944	59.70	2.880
0.81	4.813	36.90	1.776	63.10	3.037
0.80	4.801	33.40	1.603	66.60	3.197
0.79	4.788	29.90	1.432	70.10	3.356
0.78	4.776	26.30	1.256	73.70	3.520
0.77	4.764	22.30	1.062	77.20	3.678
0.76	4.751	19.20	0.912	80.80	3.839
0.75	4.739	15.60	0.739	84.40	4.000
0.74	4.727	12.00	0.567	88.00	4.160
0.73	4.714	8.40	0.396	91.60	4.318
0.72	4.702	4.76	0.224	95.20	4.476
0.71	4.690	1.10	0.052	98.90	4.638
0.707	4.686	0.0	0.000	100.00	4.686

Definitions & Abbreviations Used in Calorimetry

VO_2 Oxygen consumption

VCO_2 Carbon dioxide production

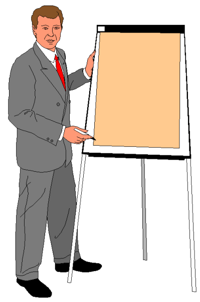
RQ Respiratory quotient = VCO_2 / VO_2 for the cell

RER Respiratory exchange ratio = VCO_2 / VO_2 measured from expired air

Kcal/L The energy release from metabolism for each L of VO_2

Bomb Calorimeter: instrument used to combust food and measure the VO_2, VCO_2, and heat release.

Respirometer: instrument that quantifies the body's VO_2 and VCO_2.



QUESTIONS

1. Why are the Kcals/g values less for the body, especially for protein catabolism?

2. Which type of molecule provides the greatest amount of energy per mass?

3. If fat provides a greater store of energy, why does CHO provide more energy relative to VO_2?
(hint, think back to catabolism!!)

4. What is the RQ, and why is it important to assess during rest and exercise?

Open-circuit Indirect Calorimetry

When concerned with exercise, the predominant application of indirect calorimetry is for the measurement of **oxygen consumption** (VO_2). The measure is used to assess the *metabolic intensity* of the exercise.

Indirect Gas Analysis Calorimetry

Fundamental Principles

1. That the volume of oxygen consumed (**VO_2**) by the body is equal to the difference between the volumes of inspired and expired oxygen.

2. That the volume of carbon dioxide produced (**VCO_2**) by the body is equal to the difference between the volumes of expired and inspired carbon dioxide.

Measurements From Indirect Gas Analysis Calorimetry

Understanding ATPS and STPD

Gas volumes vary with temperature and pressure, thus there needs to be a standard way to express gas volumes so that pressure and temperature variations are removed.

ATPS = Atmospheric Temperature and Pressure, Saturated

- *Actual air temperature* — *= 273 + Troom in ° C*
- *Actual Pressure*
- *RH=100%* — *For a given RH, P_{H2O} varies with temperature*; *~15.5 mmHg at 18 °C*; *~ 47 mmHG at 37 ° C*

STPD = Standard Temperature and Pressure, Dry

- *273 °K = 0 ° C*
- *Standard pressure* — *760 mmHg*
- *RH = 0%* — *P_{H2O} = 0 mmHg*

$$VE_{STPD} = VE_{ATPS} * (273 / (273 + T_{room})) * ((P_B - P_{H2O}) / 760)$$

Temp (°C)	P_{H2O} (mmHg)
14	12.9
15	13.5
16	14.1
17	14.9
18	51.5
19	16.5
20	17.5
21	18.7
22	19.8
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.3
29	30.0
30	31.8
31	33.7
32	35.7
33	37.7
34	39.9
35	42.2
36	44.6
37	47.1
38	49.4
39	52.0
40	54.7

System	Temperature	Pressure	RH	Water Vapor
Douglas bag	Room Temp	Barometric pressure	100%	Depends on gas temp
Expired turbine at mixing chamber	Room Temp^	Barometric pressure	100%	Depends on gas temp
Expired turbine at mouthpiece	37 °C*	Barometric pressure	100%	Depends on gas temp
Inspired turbine or flow meter	Room Temp	Barometric pressure	depends on gas temp and water vapor pressure	Depends on gas temp and RH

^preferably, gas temp is measured at mixing chamber
*assumes normal core temperature. Otherwise, gas temp = core temp

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Calculating VO_2

1 $$VO_2 = V_IO_2 - V_EO_2$$

as a gas volume = the volume of air multiplied by the gas fraction;

2 $$VO_2 = (V_I F_IO_2) - (V_E F_EO_2)$$

where F_IO_2 = fraction of oxygen in inspired air = 0.2095
F_EO_2 = fraction of oxygen in expired air = variable

To prevent the need to measure both inspired and expired volumes, and introduce the measure of carbon dioxide, the **Haldane transformation** is used.

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Haldane Transformation

This tranformation assumes that nitrogen is physiologically inert. Therefore, ***the volume of inspired nitrogen must equal the volume of expired nitrogen***.

3 $(V_I F_I N_2) = (V_E F_E N_2)$

4 $V_I = (V_E F_E N_2) / F_I N_2$

5 $V_I = V_E (F_E N_2 / F_I N_2)$

where $F_I N_2$ = fraction of inspired nitrogen = 0.7808

therefore,

$$F_E N_2 = [0.99063-(F_E O_2 + F_E O_2)]$$

Thus,

6 $V_I = V_E ([0.99063-(F_E O_2 + F_E O_2)] / 0.7808)$

Incorporating equation ***6*** into ***2*** provides the final equation to calculate VO_2.

$$VO_2 = (V_E ([0.99063-(F_E O_2 + F_E O_2)] / 0.7808) \times F_I O_2) - (V_E F_E O_2)$$

V_I

Calculating VCO_2

$$VCO_2 = V_E CO_2 - V_I CO_2$$

where $F_I CO_2$ = fraction of carbon dioxide in inspired air = 0.0003

$$VCO_2 = (V_E F_E CO_2) - (V_I \times 0.0003)$$

Calculating RER

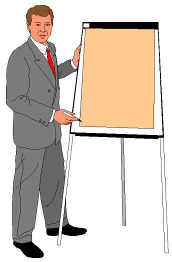
$$RER = VCO_2 / VO_2$$

RQ vs RER

The *RQ and RER are the same measurement*, yet as the components of the measure are *obtained differently* (cell respiration vs exhaled air from the lung), under certain circumstances the *values can differ*.

The maximal range of RQ is from 0.7 to 1.0

The range of RER may vary from <0.7 to >1.2



QUESTIONS

1. Why can RER vary so much more than RQ?

2. How do these differences alter test requirements and data interpretations?

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The assumption of equality between RQ and RER cannot be made during the following;

1. **Metabolic acidosis** - inflates VCO_2 causing RER>1.0

2. **Non-steady state exercise** - lower than expected VO_2 and a likelihood for an inflated VCO_2 and RER.

3. **Hyperventilation** - causes a higher VCO_2 and inflates the RER.

4. **Excess post-exercise VO_2** - sustained elevated VO_2 can cause RER to be lower than expected.

5. **Prolonged exercise** - if CHO nutrition was poor and muscle and liver glycogen are low, the longer the exercise session that greater the amino acid oxidation.

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Calculating Energy Expenditure

To calculate energy expenditure most accurately, you need to know the following;

1. **VO_2**
2. **RER**
3. **RER caloric equivalent**
4. **Exercise duration**

Kcal = **VO_2** (L/min) x **RER caloric equivalent** x **time** (min)

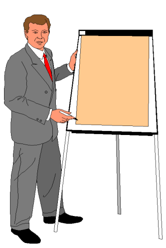
For example,

when exercising at a VO_2 = 1.5 L/min and RER = 0.9 for 30 min;

Kcal = **1.5** (L/min) x **4.924** x **30** (min)

= **221.6**

QUESTIONS



1. Where does the value of 4.924 come from?
2. Assuming all assumptions are met for calculating fat and carbohydrate contributions to energy expenditure, how much energy (kcals) came from these fuels?
3. Assuming 4 kcal/g and 9 kcal/g as the caloric densities for fat and carbohydrate, respectively, how much fat and carbohydrate were used during this exercise condition?

Economy vs. Efficiency

Economy - refers to the energy cost of an exercise condition.

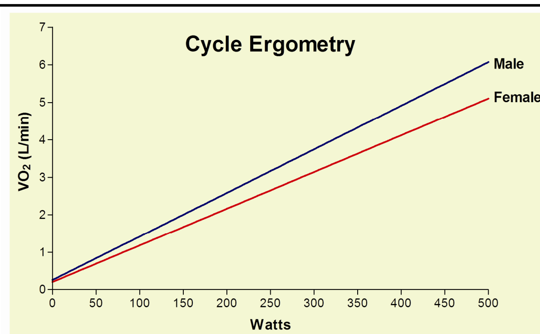
Efficiency - the mechanical energy produced relative to the metabolic energy expenditure

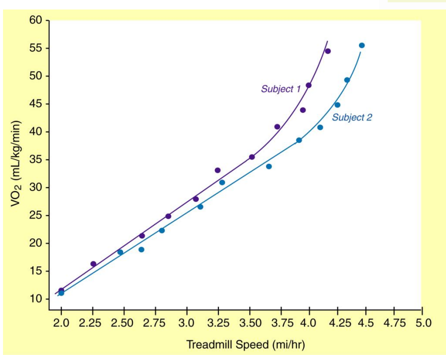
For example;

The VO_2 during running is often termed “running economy” or “submaximal VO_2”. A person with a lower running VO_2 for a given pace has better *economy*.

Conversely, if a person requires a smaller increase in VO_2 during a change in running pace, then that person has better *efficiency*.

Economy and efficiency can be related, but the terms should not be used interchangeably.





Computation Examples in Indirect Calorimetry

Convert the following environmental gas volumes to STPD based on the conditions of : ***Tr=24.0 °C; P_B=635 mmHg; RH=100%; P_{H2O}=22.4 mmHg***

12 L/min ; 59 L/min ; 130 L/min ; 180 L/min

Compute VO_2, VCO_2, & RER for the following tabled values and environmental conditions above.

Time	VE (ATPS)	FEO_2	$FECO_2$
0	9.35	0.1658	0.0390
4	35.14	0.1496	0.0480
8	72.37	0.1575	0.0499
12	175.03	0.1784	0.0362

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Answers

Expired volume correct to STPD:

12 = 8.89 L/min ; 59 = 43.71 L/min ; 130 = 96.31 L/min ; 180 = 133.36 L/min

VO_2, VCO_2 and RER Questions:

Time	VE (STPD)	FEO_2	$FECO_2$	VO_2	VCO_2	RER
0	6.93	0.1658	0.0390	**0.312**	**0.268**	**0.859**
4	26.04	0.1496	0.0480	**1.645**	**1.242**	**0.755**
8	53.62	0.1575	0.0499	**2.823**	**2.660**	**0.942**
12	129.68	0.1784	0.0362	**3.866**	**4.656**	**1.204**

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