Physiological Thermodynamics:
The Determination of Caloric Content of Polyunsaturated Fats at Room Temperature

Student's Name	
Date Experiment Performed	
Professor Sign-Off	
Course	

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Introduction [4]

As you recall from your introduction to thermodynamics in General Chemistry I (CHEM 121 at WNCC), heat flows from an object of hotter temperature to an object of cooler temperature.

This term (heat) is all fine and dandy --it doesn't, though, give us a measure in terms of mass and/or amount. To that end we use the term Joules in science. Joules aren't as widely known a term as are calories in the U.S., therefore, **one calorie is equal to 4.184 Joules**.

One **calorie (cal)** is defined as the amount of heat necessary to raise the temperature of 1 gram of water by 1° C -- a little less than a perfect definition, yet close enough for our purposes. One **Calorie (Cal or kcal)** is 1000 calories or 1 kilocalorie (kcal). The kcal is the unit we use for "food calories".

As you remember from General Chemistry I Laboratory, we can use Styrofoam cups and cardboard lids to make a rudimentary calorimeter to study the heats of reactions in studying Hess' Law. This experiment is a bit different as we wish to know the caloric content of a polyunsaturated fat.

Why would we want to know this? There are many reasons. For this course, we wish to know from a practical digestive perspective as it impacts the heat generated (or stored) by a human being.

When discussing human heat regulation, the unit "watt" is a fairly common way in which to discuss this regulation. Watt is a term that we have some knowledge of. We are familiar with the term "kilowatt" from our electrical bills at home, for example. What, though, does watt mean in terms of something we have either studied or can easily relate to? A watt is 1 J/sec or 0.24 calories/second. One watt is also equal to 1.44 X 10^{-2} kcal/minute. What does this mean in terms of something we can recognize from our daily life? The table, below, summarizes various exercise activities performed by men and by women.

Exercise Activities			
	Light Exercise	**Heavy Exercise**	**Very Heavy Exercise**
Examples	**Walking, fishing, golfing**	**Ice skating, jogging**	**Running fast, racquet ball**
Male	**2-5 Cal/min**	**7.5-10 Cal/min**	**≥ 12.5 Cal/min**
Female	**1.5-3.4 Cal/min**	**5.5-7.4 Cal/min**	**≥ 9.5 Cal/min**

At 10 Cal/min of exercise, a person would generate about 0.694 kW of energy, whilst, exercising at 12.5 Cal/min would generate about 0.868 kW of energy. Since 1 kW is about 1.34 horsepower (or about a quarter horse and a Shetland pony), heavy exercise is about 0.92 horsepower and very heavy exercise is about 1.2 horsepower, for perspective.

In humans, as in other mammals, heat is both generated and lost. The table, below, summarizes the sources of heat generated and heat lost in and by the human body:

Heat	
Generated	**Lost**
Q_M = heat generated from Metabolism; 80-1600 W depending on the circumstances	**Q_C = Convective Heat Loss**
	Q_R = Radiative Heat Loss
	Q_S = Heat loss from evaporation of Sweat
	Q_L = heat loss via Lung water loss; a constant: 10.5 W

Heat convection is defined as "[h]eat transfer in a gas or liquid by the circulation of currents from one region to another." [1]. Radiative heat loss is defined as "[a p]rocess by which energy is emitted by a warm surface. The energy is electromagnetic radiation and so travels at the speed of light and does not require a medium to carry it." [2]). Evaporative loss is defined as "The transfer of heat when a liquid is converted to a gas; when water is converted from a liquid to a vapor, heat is utilized. … [i.e.,] heat is transferred from the body to water, turning it to water vapor." [3]). While Sweating occurs on the surface of the body, the heat loss due to lung water loss is of the same concept.

We can easily calculate Q_C, Q_R and Q_S:

$$Q_C = \frac{7.1W}{m^2\ K} * Surface\ Area\,(m^2) * \left(T_{skin} - T_{air}\right)$$

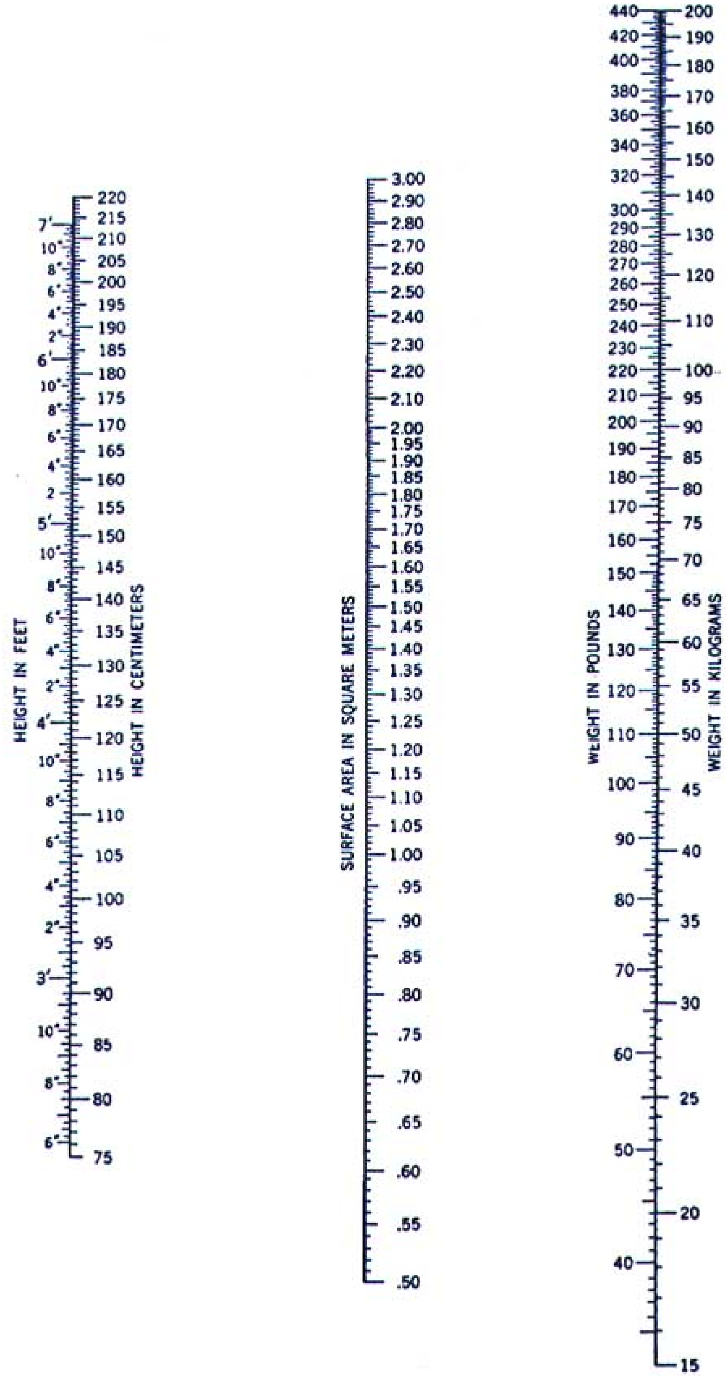
$$Q_C = \frac{7.1W}{m^2\ K} * SA * \left(\Delta T\right)$$

$$Q_R = \frac{6.5W}{m^2\ K} * SA * \left(\Delta T\right)$$

$$Q_S = \frac{674W\,h}{kg} * \frac{kg\ \ sweat\ \ produced}{hour}$$

Where 7.1 (W/m^2-K) is a convective constant; 6.4 (W/m^2-K) is a radiative constant; 674 (W-h/kg body weight) is a sweat constant; Surface Area is reported in units of square meters (one must look this up and use a nomogram, right. This nomogram is from [6] and is used within the public domain and educational use permissions' copyright laws of the US.

Note, too, that the ΔT term is ALWAYS set up as the difference between the skin and air temperature regardless of which we're solving for. Additionally, at a constant temperature, $\mathbf{Q_M = Q_C + Q_R + Q_S + Q_L}$. Lower case subscripts of the upper case letters are as acceptable as the upper case letters. Let's look at two examples and see how this information may be applied.



What is YOUR surface area?

________________ m^2

Example 1: The "average" person" at rest emits 100 W of heat.
If the surface area of the person is 1.975 m^2 and the skin temperature is 37° C and the air temperature is 14.4° C, how much sweat will be produced by this person?

1) the temperature difference is 22.6 K

2) the SA is 1.975 m^2

3) Qm= 100 W

4) Qc= (7.1)(1.975)(22.6) = 316.9 W

5) QR= (6.5)(1.975)(22.6) = 290.1 Watts

6) Qs= (674)X

7) Ql= 10.5 W

8) Qm= Qc+ QR+ Qs+ Ql

rearrange step 8 and solve for Qs:

Qm-Qc-QR-Ql= Qs

100 -316.9 -290.1 -10.5 = -517.5 W = Qs

674X = -517.5

X = -0.768 kg sweat produced per hour

Note that the answer is a negative number! This means that the person does not produce sweat and is cold and requires heat.

This example was actually used to prove that a former administrator at WNCC needed to have his office heat vent repaired.

Example 2: The "average" person" at rest emits 100 W of heat. If the surface area of the person is 1.975 m^2 and the skin temperature is 37° C and the air temperature is 38° C, how much sweat will be produced by this person?

1) the temperature difference is -1 K

2) the SA is 1.975 m^2

3) Qm= 100 W

4) Qc= -14 W

5) QR= -13 Watts

6) Qs= ?

7) Ql= 10.5 W

8) Qm= Qc+ QR+ Qs+ Ql

rearrange step 8 and solve for Qs:

Qm-Qc-QR-Ql= Qs

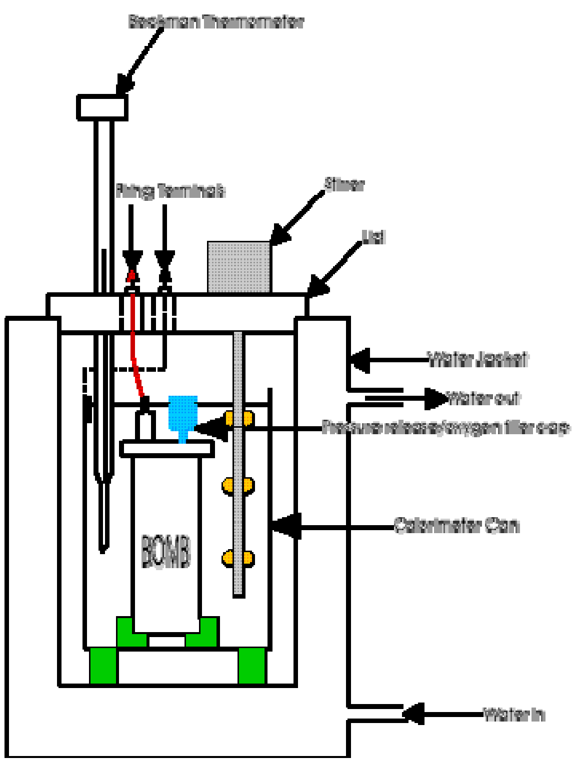
100 -(-14) -(-13) -10.5 = 116.5 W = Qs

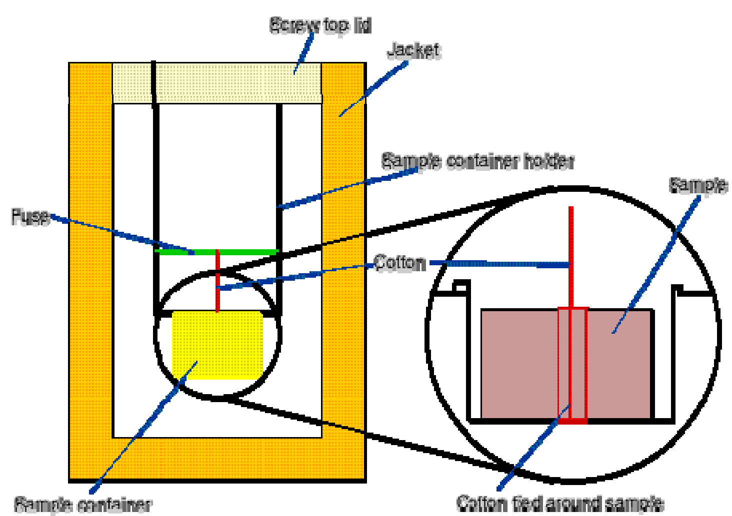
674X = 116.5

X = 0.173 kg sweat produced per hour. This is about 173 mL/hour. At about 30 oz per mL, this is about 5.8 oz/hour.

Remember, though, that these are approximations and take into account no other biological processes that may or may not impact the final heat regulating outcome, e.g., thyroid function, hypothalamic function.

We've seen how energy can be generated or lost in the body – how, besides using metabolic studies, might we determine the energy content of foods so that we can use those energy sources? The most common (and, hence, most expensive) way in a lab is to use a bomb calorimeter (Figure, left, below, is a typical bomb calorimeter and figure, right, below, is the internal representation of the steel bomb calorimeter – images from [5] and are used within the public domain and educational use permissions' copyright laws of the US:





As these calorimeters are a bit too pricey for most basic science labs at the sophomore level, some adjustments must be made. (Remember, too, that our dietary intake plays a role in our heat production a) directly by giving us fuel and b) indirectly through the process of dietary induced thermogenesis (DIT; see NUTR 223 lecture notes).[7])

A simple apparatus to determine the caloric content of polyunsaturated fats can be assembled as follows, see Figure at right. This apparatus works nicely for heating a fixed amount of water 10° C above its starting point knowing the mass difference in the amount of the oil burned.

Note that the image is NOT a blatant advertisement for Sierra Mist – these half-soda cans just happened to be handy and that's what I used for the experimental work-up for this experiment.

Materials

Instead of keying out an actual list of items you need for this experiment, the items and supplies that you need are in the following two images:

The oil lamps may already be set up for you – you'd have to trim the wick, then.

You will be determining the caloric content of only one of these oils (peanut, corn, vegetable or canola) – not of all four.

Method [8]

Set up your apparatus as illustrated in the close-up image, right:

Note that the two rings are used to hold the water vessel (half-soda can) so that it won't fall over and spill into your oil lamp. Do not light the wick until later, when instructed.

Place 100 mL of tap water in the half-soda can.

Record the Room Temp: _______°C

Record the Water Temp: _______°C

The water temp needs to be about 10°C cooler than room temp is it? ________

Don't worry if they're close – it all works out just fine.

What oil have you been assigned to study? ___________________________

Pour your oil into the 50 mL beaker until it's about the height that you can see in the image, right.

Allow the oil lamp portion of your combustion calorimeter to stand for about 10 minutes so that the oil will flow up the wick in a uniform manner. After that, adjust the wick so that it is sticking up above the wire holder about a cm or so. Light the wick and see how it burns. If it's too sooty, blow it out and carefully trim the wick to narrow it up – soot will "cake out" on the under-surface of the can and give you false readings (very similarly to how scale causes boiler explosions – remember from CHEM 121?). Re-light the wick and see how it burns – if it's too tall, blow it out and trim a little off the top edge and try it, again. If it's too short, blow it out, **let it cool**, then pull a little more above the wire holder and relight it and see how it burns. Once you have the flame adjusted, set the lamp aside to cool.

Once the lamp has cooled to room temperature, take it to the balance you have chosen to use for this experiment (remember experimental error from CHEM 121, 122 and/or 220?) and obtain its mass – remember to record all of the numbers from the balance. Record your data on the data table, below.

Place the oil lamp, now, beneath the water vessel and lower (if necessary) or raise (if necessary) the water vessel until the bottom of the ring holding the half-soda can is approximately 6-8 mm above the top of the beaker.

Carefully light your oil lamp and slide it beneath the water vessel so that the flame is centered on the bottom of the can. Record the starting temperature of your water at this point in the data sheet, below, and allow the lamp to burn until the water temp has risen 10°C above what you started at. (Don't worry if your water temperature goes slightly above 10°C greater than what you started with – in our preliminary trials, my son and I had a 13-15°C temperature differential and the data came out just fine.) Record that temperature in the data sheet below.

Slide the lamp out carefully and blow it out and let it set aside from the water vessel for 10 minutes. After that 10 minutes have passed, take the lamp back to the balance and re-mass it, recording its mass, below. Let it stand another 20 minutes before you repeat the procedure.

During the 20 minute wait, remove the water vessel from the rings and pour out the water. Check the bottom of the can for sooting – if there is soot, you'll need to trim the wick a little narrower than it is. Scrub off as much of the soot as you can with a paper towel, dry it off and refill it with another 100 mL of fresh water that is about 10°C cooler than room temperature and return it to its place between the rings. Additionally, at this time, pull the wick up about 3-5 mm if necessary and trim it before use for the second trial.

Once the 20 minute period has passed, repeat what you did for Trial one, using your final weight from Trial 1 as the initial weight of the oil lamp in Trial 2. Remember to record your data, below, as you did in Trial 1.

When you have completed your experiment, dispose of the water down the sink. Dispose of the oil, there, as well. Wash your glassware and return it to the cabinet. Return the oil lamp apparatus and half-soda can to where you obtained them, wash down your area, followed by your hands and you're on your way.

Data Table

Oil Used in This Experiment			
		Trial 1 Data	Trial 2 Data
Line 1	Room Temp (°C)		
Line 2	Final Water Temp (°C)		
Line 3	Initial Water Temp (°C)		
Line 4	Water Temp Increase (°C)		
Line 5	Volume Water (mL)		
Line 6	Initial Mass of Oil Lamp (g)		
Line 7	Final Mass of Oil Lamp (g)		
Line 8	Mass of Oil Combusted (g)		
Line 9	Heat Absorbed by Water (kcal)		
Line 10	Kcal/g oil		

Lines 1-8 are self-explanatory.

To calculate the value for line 9, do the following:

$$\Delta H = \frac{(100)(line\ 4\ value)}{1000} = \underline{\qquad}\ kcal$$

100 is the mass of your 100 mL of water multiplied by the heat capacity of water multiplied by the density of water; the "Line 4 value" is from line 4 of your data; the 1000 converts your answer from calories to kcalories.

To calculate the value for line 10, do the following:

$$\Delta H_{oil\ combustion} = \frac{Line\ 9\ value}{Line\ 8\ value} = \frac{kcal\ of\ energy}{gram\ of\ oil}$$

Results

1) Based on your data, how much energy is there in a gram of fat on average?

2) Assuming 50% efficiency in the burning of your fat, how much energy is there per gram of fat from your experiments? Show your work.

3) Design a scheme whereby you could use a similar set-up to determine the energy in glucose. Attach it on a separate piece of paper (by staple, of course) for turn-in.

Conclusions

What do you conclude from this experiment? Why?

References

[1] http://medical-dictionary.thefreedictionary.com/convection

[2] http://www.answers.com/topic/thermal-radiation

[3] http://www.ces.ncsu.edu/depts/poulsci/tech_manuals/hot_weather_management.html

[4] http://www.wncc.edu/~carman/km121lex/week7.pdf

[5] http://www.acornusers.org/education/Thesis/BombCalorimetry.html

[6] http://www.ucihealth.com/MS/nomogram.htm

[7] http://www.wncc.edu/~carman/nut223lx/nutrwk2.pdf

[8] Roberts, Hollenberg and Postma. **General Chemistry in the Laboratory, Third Edition.** (W.H.Freeman & Co: Sydney) ©1990

Appendix 1 – Sample Data Sheet

Oil Used in This Experiment		Canola	
		Trial 1 Data	Trial 2 Data
Line 1	Room Temp (°C)	20	19.5
Line 2	Final Water Temp (°C)	31.0	31.0
Line 3	Initial Water Temp (°C)	18.0	17.8
Line 4	Water Temp Increase (°C)	13.0	13.2
Line 5	Volume Water (mL)	100	100
Line 6	Initial Mass of Oil Lamp (g)	62.4943	62.2362
Line 7	Final Mass of Oil Lamp (g)	62.2362	62.0127
Line 8	Mass of Oil Combusted (g)	00.2581	00.2235
Line 9	Heat Absorbed by Water (kcal)	1.3	1.32
Line 10	Kcal/g oil	5.037	5.906
These trials done by Tyler – 20 February 2006 – Broken wrist and all.			

This experiment written up 18 January 2007, 1432 hours, PST.