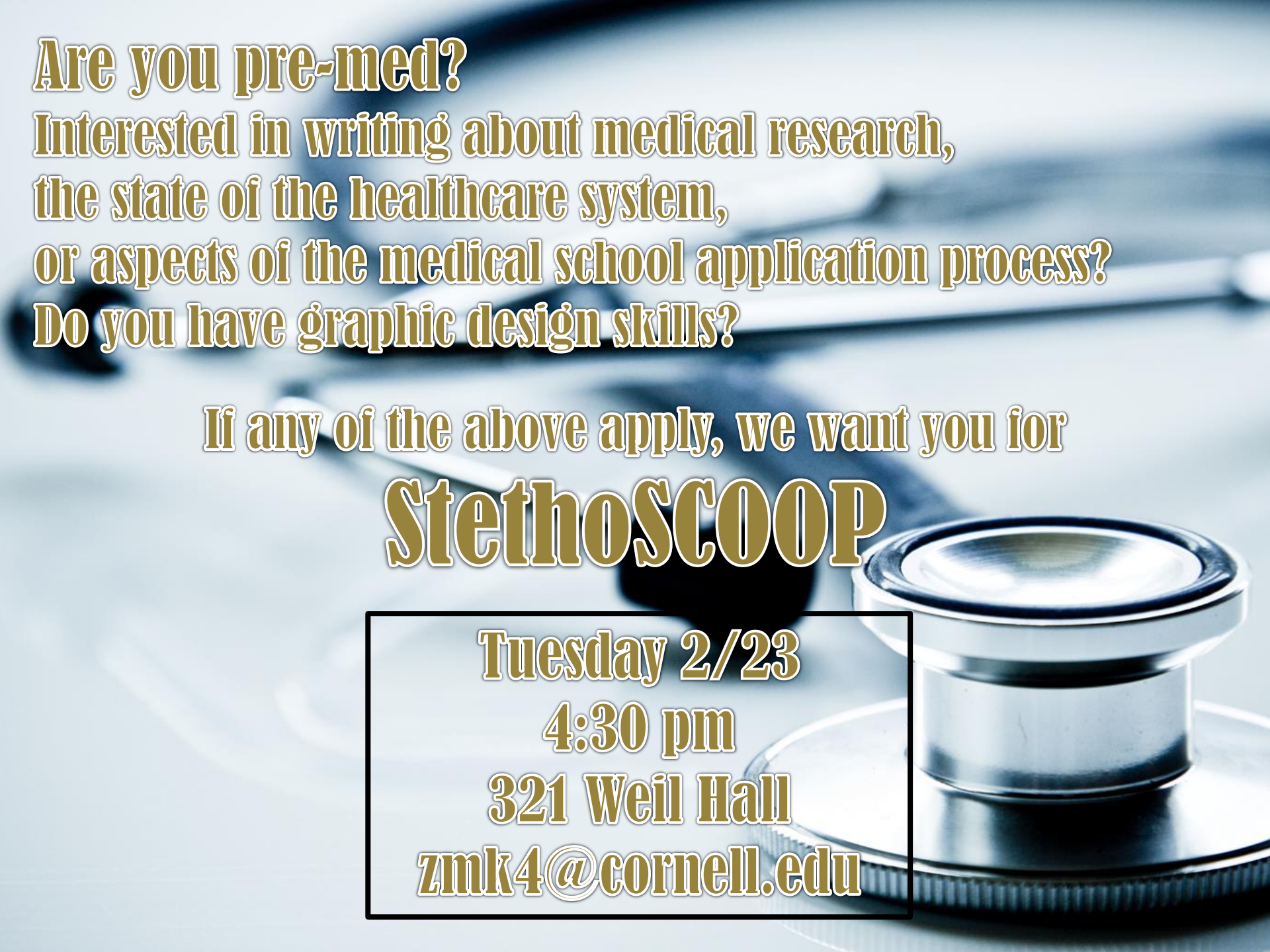
Energetics of aerobic activity

Lecture 6

17 Feb 2016

Cole Gilbert


Are you pre-med?
Interested in writing about medical research,
the state of the healthcare system,
or aspects of the medical school application process?
Do you have graphic design skills?
If any of the above apply, we want you for
StethoSCOOP
Tuesday 2/23
4:30 pm
321 Weil Hall
zmk4@cornell.edu

Course Announcement

Prelim 1 is a 50 min exam, Friday 4 March at 2:30PM in Call Auditorium

If you require a makeup exam, please sign up using the link
https://www.wejoinin.com/sheets/opgdb
before Monday, February 22, 9AM, to select a time to take the makeup

In addition, you must turn in a written excuse explaining why you can not take the exam at the 2:30 time, signed by a supervisor

We will send you your room assignment after we know how many students need certain times

If you are an SDS extra time student, please turn in your paperwork

NO DISCUSSION SECTIONS during the week of BioG 1440 exams

Where we're going

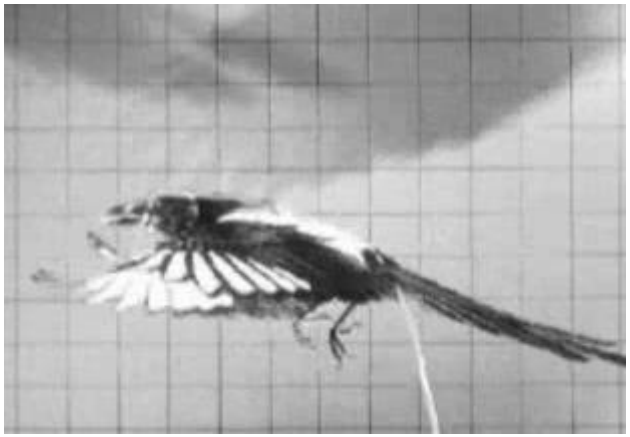
1. Measuring energy consumption
2. Basal (standard) metabolic rate
3. Maximal metabolic rate
4. Trade offs

How do we measure energy consumption ?

Respiration equation (glucose)

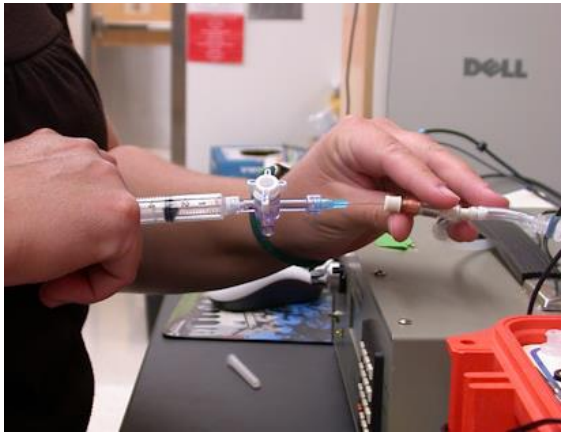
$$C_6H_{12}O_6 + 6O_2 + 29ADP + 29Pi \rightleftharpoons 6CO_2 + 6H_2O + 29\,ATP$$

continuous flow



flow rate x ($\%O_{2\ \text{fresh air}}$ - $\%O_{2\ \text{sample}}$) = O_2 consumption rate

stop flow



volume injected
x ($\%O_{2\ \text{fresh air}}$ - $\%O_{2\ \text{sample}}$)
/ duration

Respiration equation (glucose)

$$C_6H_{12}O_6 + 6O_2 + 29ADP + 29Pi \rightleftharpoons 6CO_2 + 6H_2O + 29\,ATP$$

What about burning different fuels ?

Different fuels yield different respiratory quotient (RQ) = ($CO_{2\ out}$ /$O_{2\ in}$)

Foodstuff	RQ ≈ Respiratory exchange ratio
Carbohydrates	1.0
Lipids	0.71
Proteins	0.83[a]

Fortunately for physiologists,

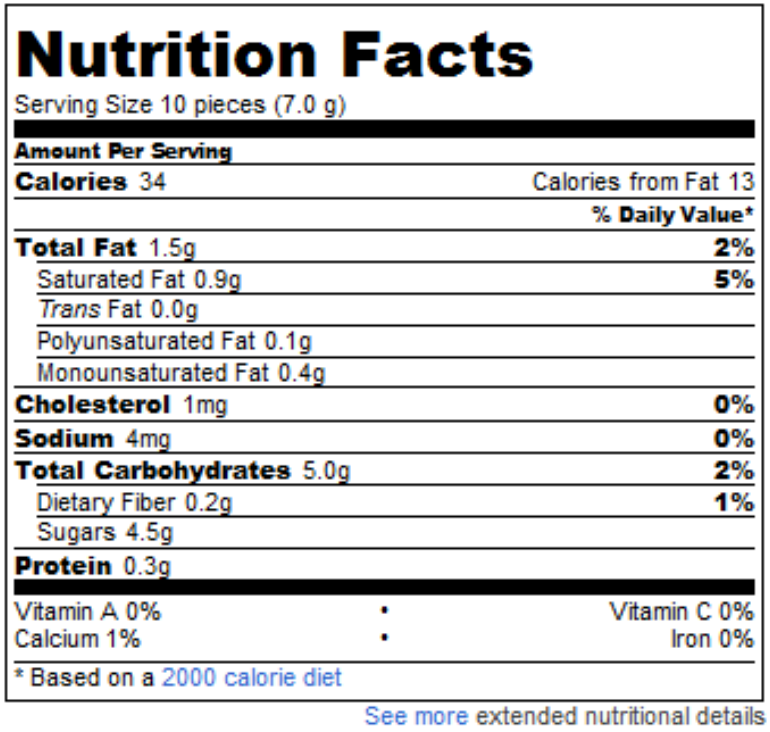
Foodstuff	Heat produced per unit of O_2 consumed (J/mL O_2)	Heat produced per unit of CO_2 produced (J/mL CO_2)
Carbohydrates	21.1	21.1
Lipids	19.8	27.9
Proteins[a]	18.7	23.3

What's a joule ?

1 calorie = 4.18 joules

(1 calorie = energy to heat 1 ml H_20 by 1 ^oC)

What’s a kilojoule of energy for your body ?



Nutrition Facts

Serving Size 10 pieces (7.0 g)

Amount Per Serving	
Calories 34	Calories from Fat 13
	% Daily Value*
Total Fat 1.5g	**2%**
Saturated Fat 0.9g	**5%**
Trans Fat 0.0g	
Polyunsaturated Fat 0.1g	
Monounsaturated Fat 0.4g	
Cholesterol 1mg	**0%**
Sodium 4mg	**0%**
Total Carbohydrates 5.0g	**2%**
Dietary Fiber 0.2g	**1%**
Sugars 4.5g	
Protein 0.3g	

Vitamin A 0% • Vitamin C 0%
Calcium 1% • Iron 0%

* Based on a 2000 calorie diet

See more extended nutritional details

Calories on US food labels are actually kilocalories

How much activity can you power with 10 M&Ms ?

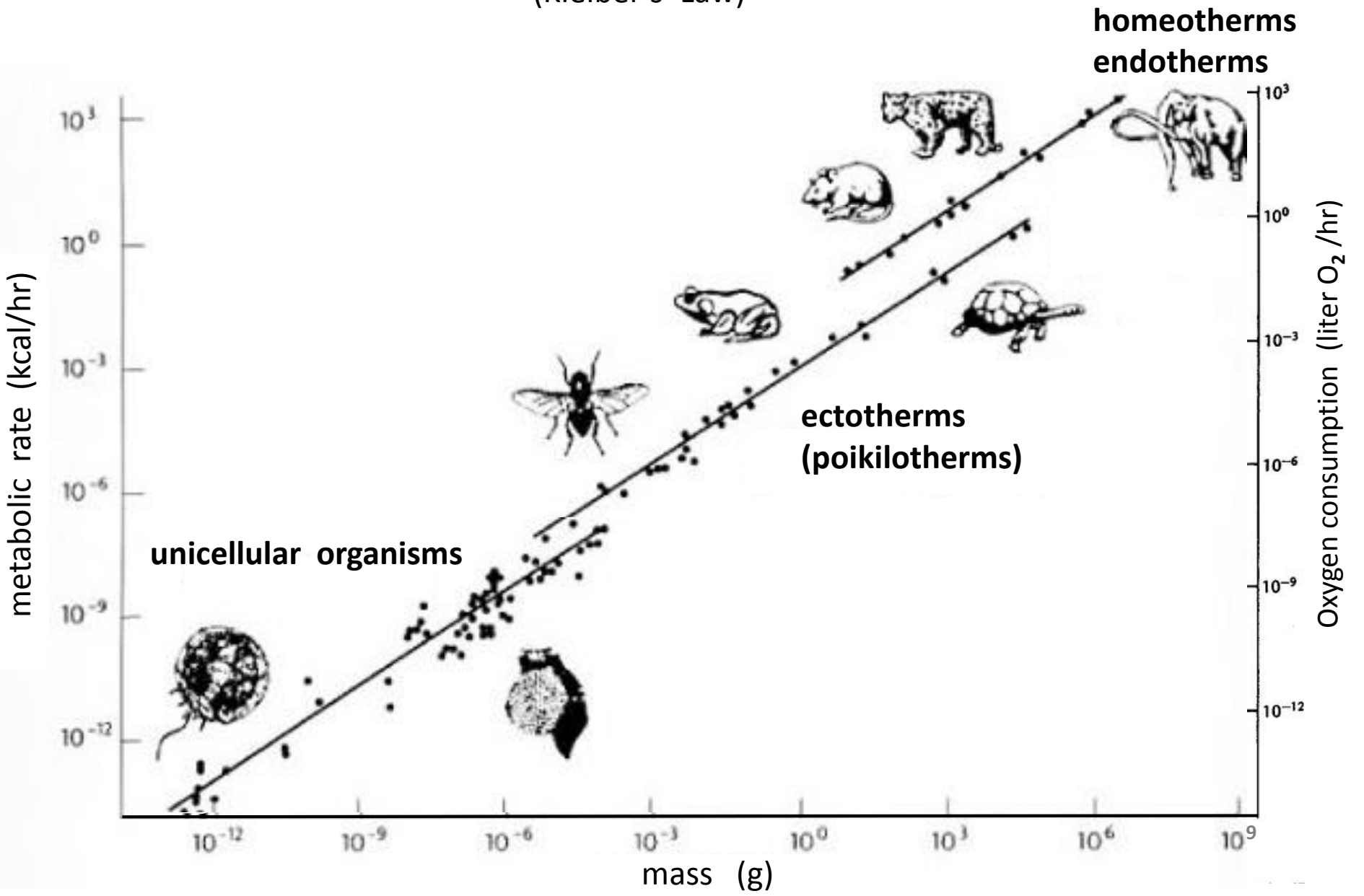
metabolic rates for young adult humans of average build

Activity	kJ/min	min/10 M&Ms
Lying down	6.3	22
Walking 4 mph (15 min mile)	21	7
Running 10 mph (6 min mile)	84	2

What factors influence metabolic rate ?

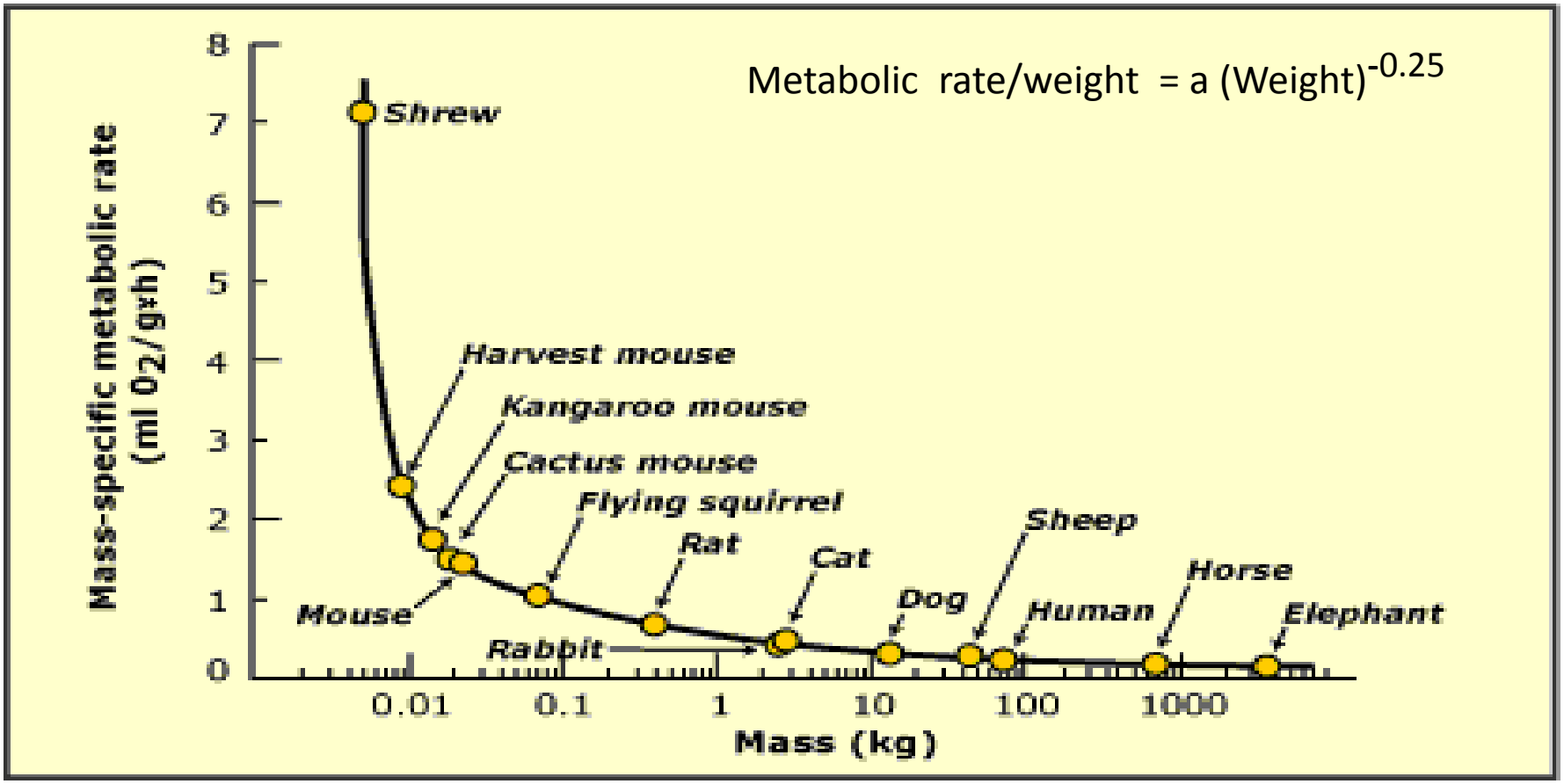
FACTORS	RESPONSE OF METABOLIC RATE
Factors that exert large effects	
Physical activity level (e.g., running speed)	↑ with rising activity level
Environmental temperature	*Mammals and other homeotherms:* Lowest in thermoneutral zone; ↑ below thermoneutral zone; ↑ above thermoneutral zone
	Fish and other poikilotherms: ↑ with increasing temperature; ↓ with decreasing temperature
Factors that exert smaller effects	
Ingestion of a meal (esp. protein-rich)	↑ for several hours to many hours following ingestion
Body size	Weight-specific rate ↑ as size ↓
Age	Variable; in humans, weight-specific rate ↑ to puberty, then ↓
Gender	Variable; in humans, ↑ in male
Environmental O_2 level	Often ↓ as O_2 ↓ below a threshold; not affected above threshold
Hormonal status	Variable; example: ↑ by excessive thyroid secretions in mammals
Time of day	Variable; in humans, ↑ in daytime
Salinity of water (aquatic animals)	Variable; in osmoregulating marine crabs, ↑ in dilute water

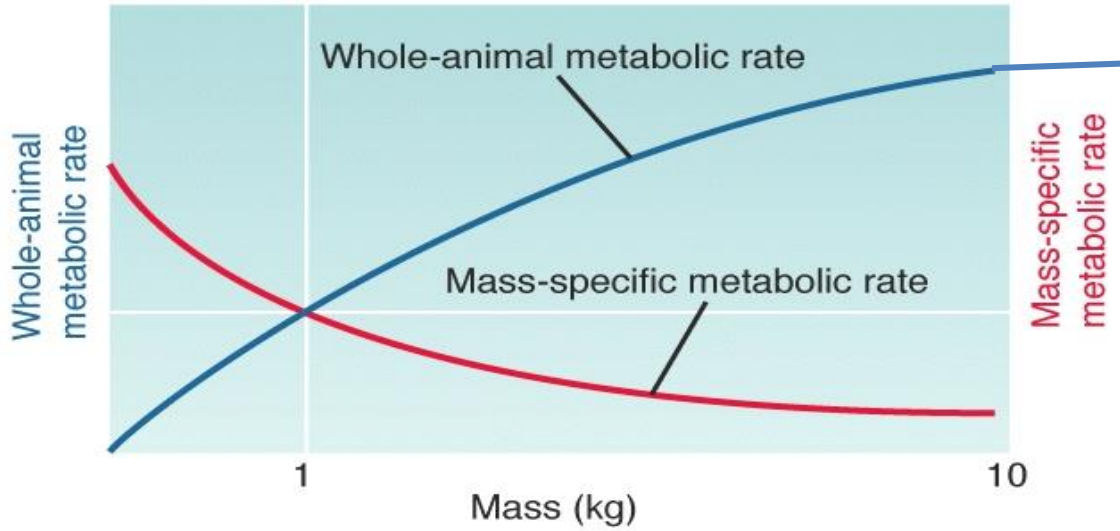
(Kleiber's Law)



BUT

Plot energy use as
weight specific metabolic rate





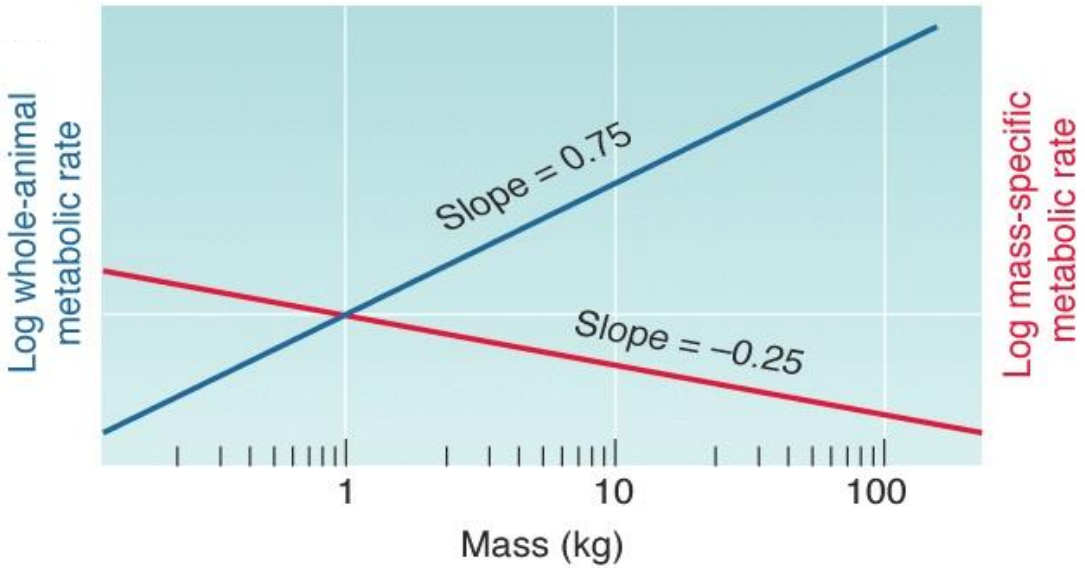
100 →

Metabolic rate = a x weight^{power}

Take logarithm of both sides — Log (Metabolic rate) = log (a) + power x log (weight)

Rearrange the right side — Log (Metabolic rate) = power x log (weight) + log (a)

Looks like the equation for a straight line — Y = mX + b



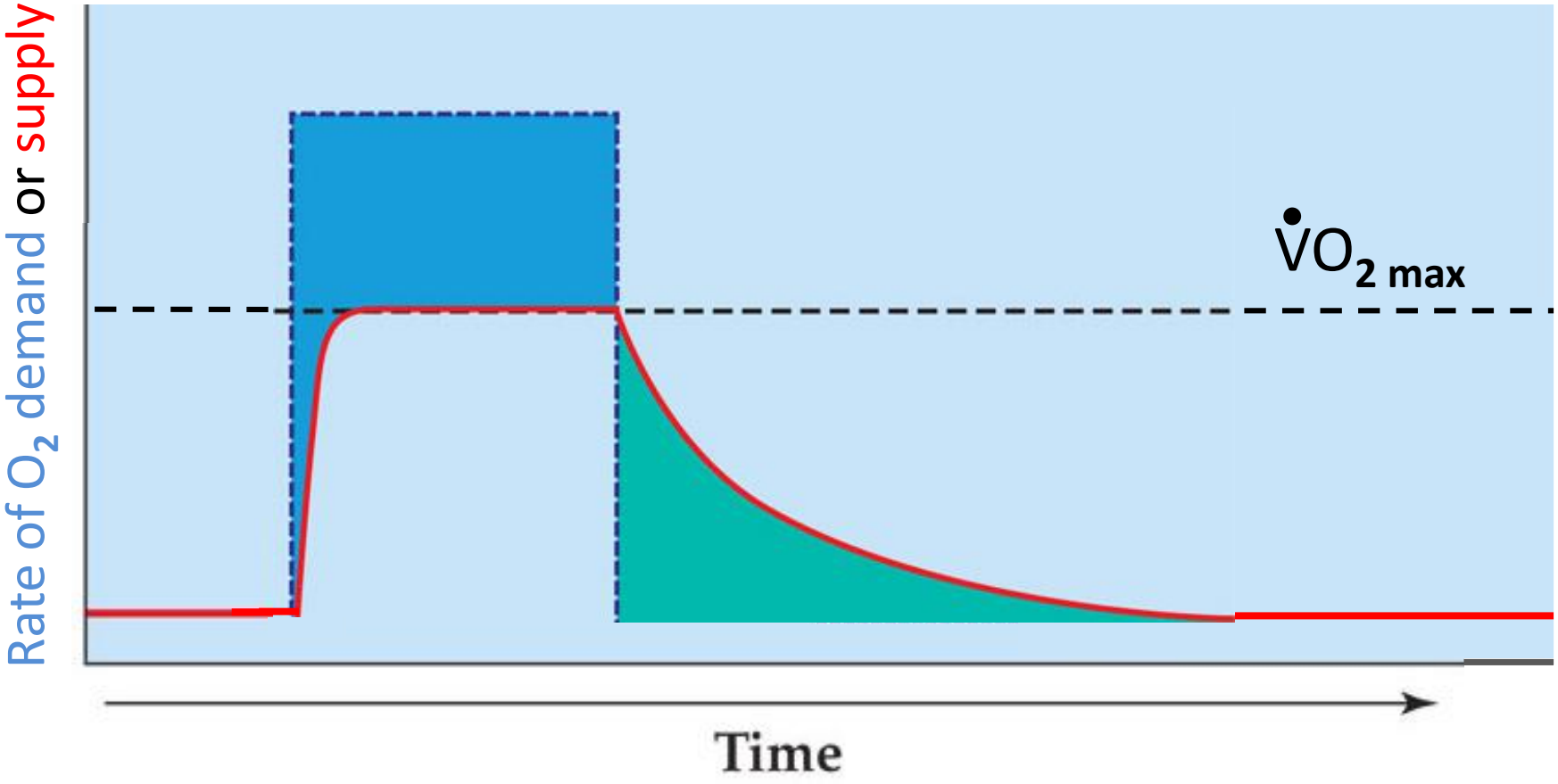
What are maximal metabolic rates $\dot{V}O_{2\ max}$?

Maximal metabolic rate $\dot{V}O_{2\,max}$
can mean the difference between life and death

Maximum rate of sustained exercise is determined by maximum aerobic ATP production

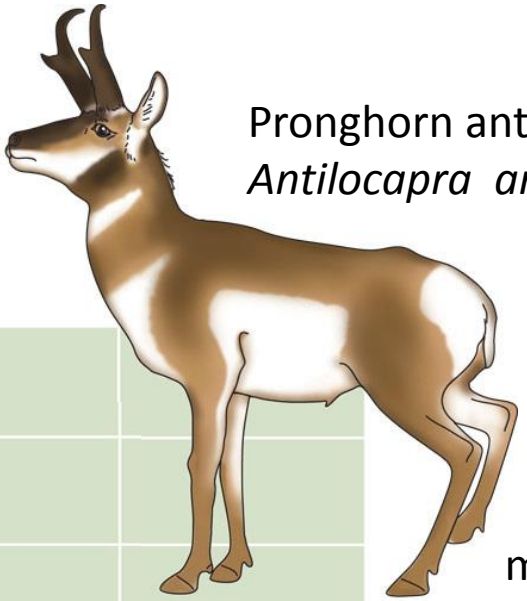
Max aerobic capacity occurs at $\dot{V}O_{2\,max}$ (max ml O_2/kg-min)

But that rate cannot be maintain for very long



Weight specific $\dot{V}O_{2\,max}$ follows same relation as $\dot{V}O_2$

But some species are outliers

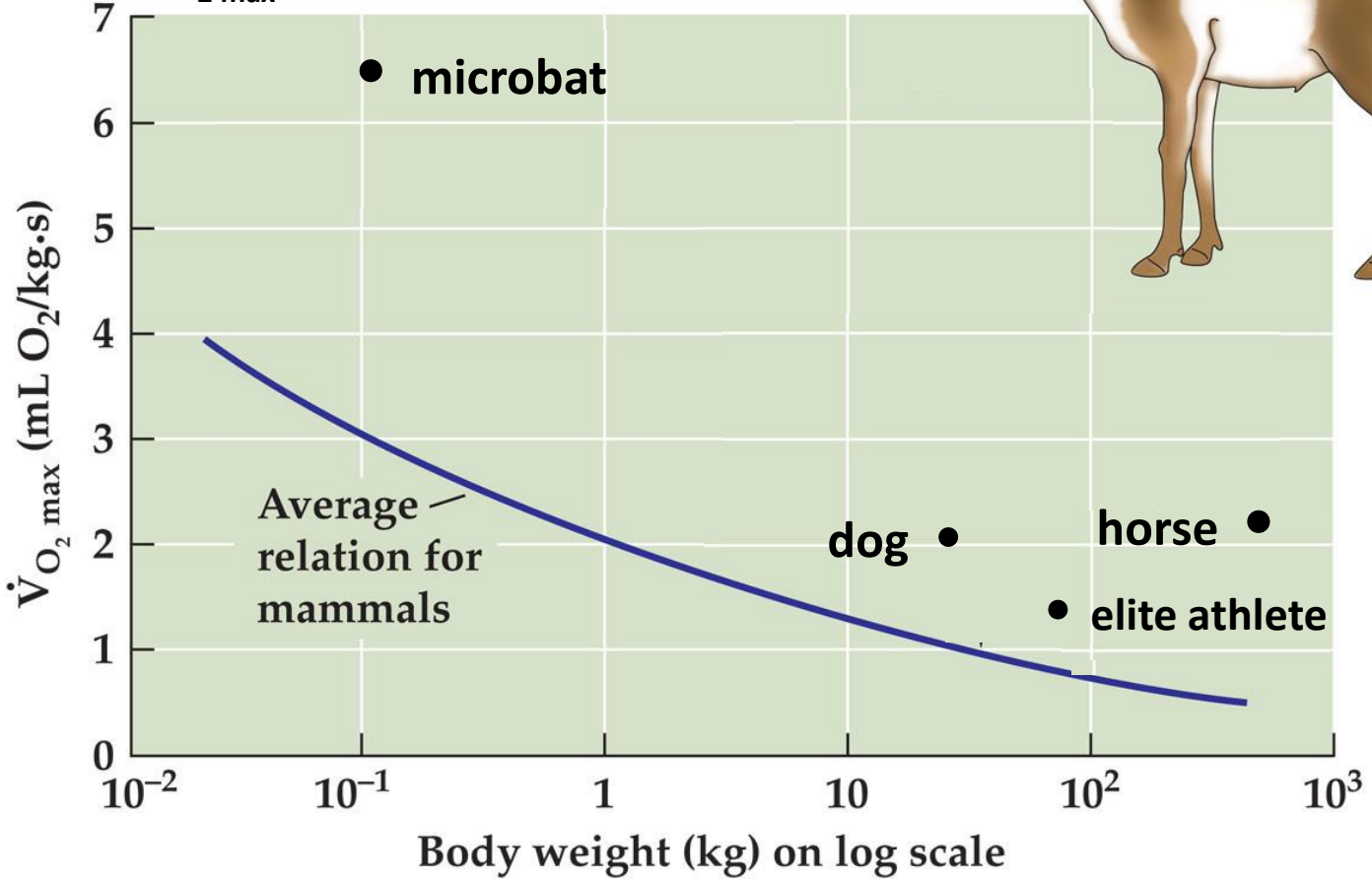


Pronghorn antelope
Antilocapra americana

massive lungs
big heart
high cardiac output
high [hemoglobin]
more muscle mass
high [mitochondria]

small stomach
low fat stores
high energy food

$\dot{V}O_{2\,max}$ for mammals of different mass



Pronghorn physiology paradox

Top speed 61mph (2x race horse)
Sustained speed 40 mph

Maximal metabolic rate measured by $\dot{V}O_{2\,max}$ is a function of many organ systems

lung volume

heart size

cardiac output

blood [hemoglobin]

capillary density

muscle mass

mitochondrial density

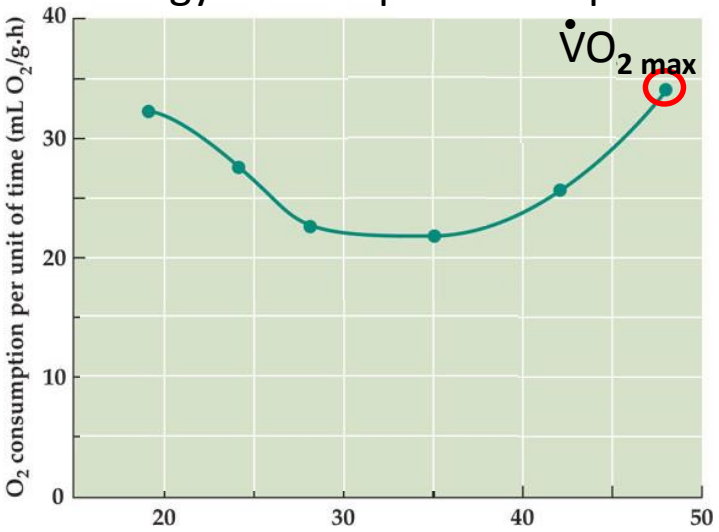
muscle temperature

with training humans can increase $\dot{V}O_{2\,max}$ up to 30 %

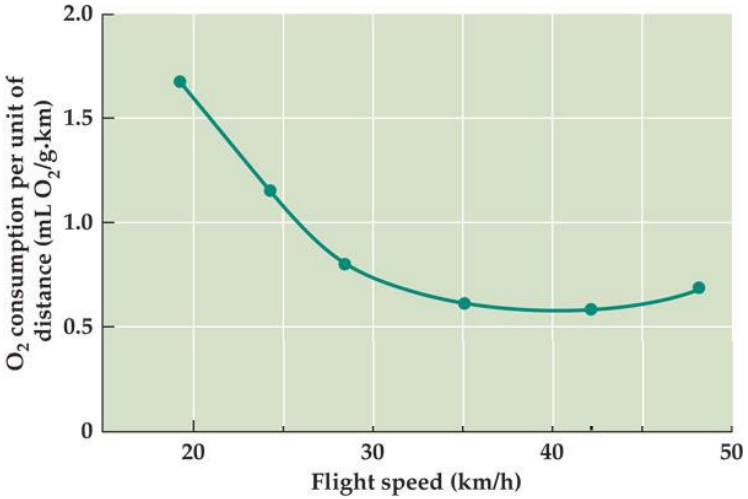
Animals face energetic trade-offs:

Budgerigar
Melopsitticus undulatus

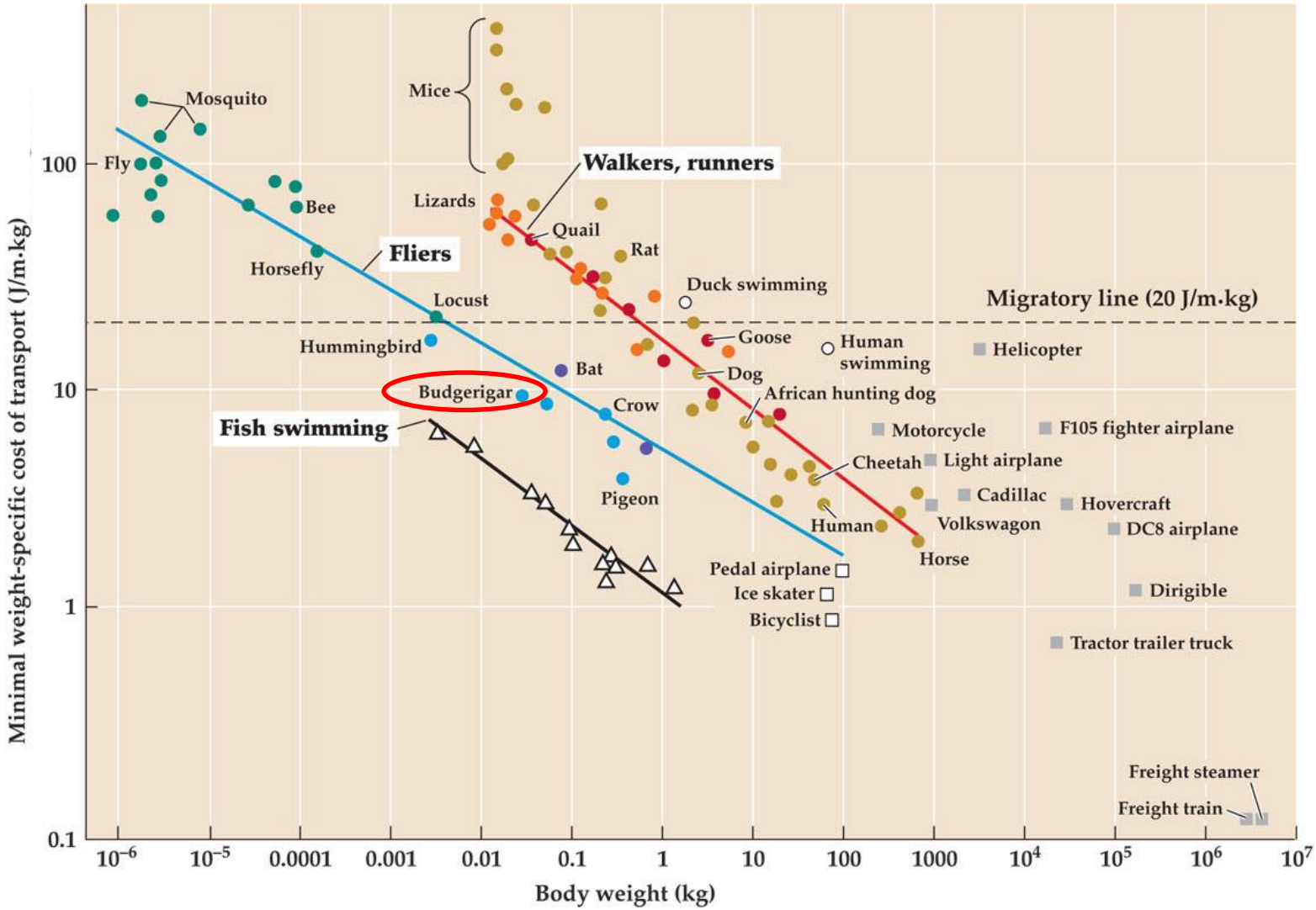
energy used depends on speed



plot energy used per distance



Minimal weight specific cost of transport depends on:



Choice of fuel is critical for migrants

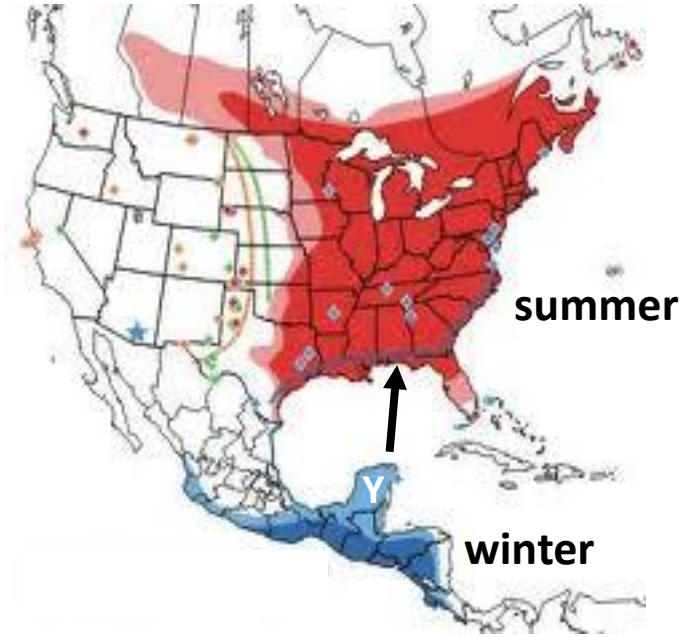
	Energy value in kilojoules (kJ) per gram
Mixed lipids	39–40
Mixed carbohydrates	17
Hydrated glycogen	4.6
Mixed proteins	18–20

Hummers gather in Yucatan (Mexico) in March
Gorge on nectar/bugs and turn them in to fat

Pre-binge:

Post-binge:

Then fly



Summary

1.

2.

3.

4.

5.

Up next – Thermal relations I