Energy and the Conservation of Energy

The most important organizing principle in all of science.

Energy can't be created or destroyed.
It can only change from one form to another.
Anything that happens involves a change in energy from one form to another.

Energy comes in many different forms.

Mechanical energy:

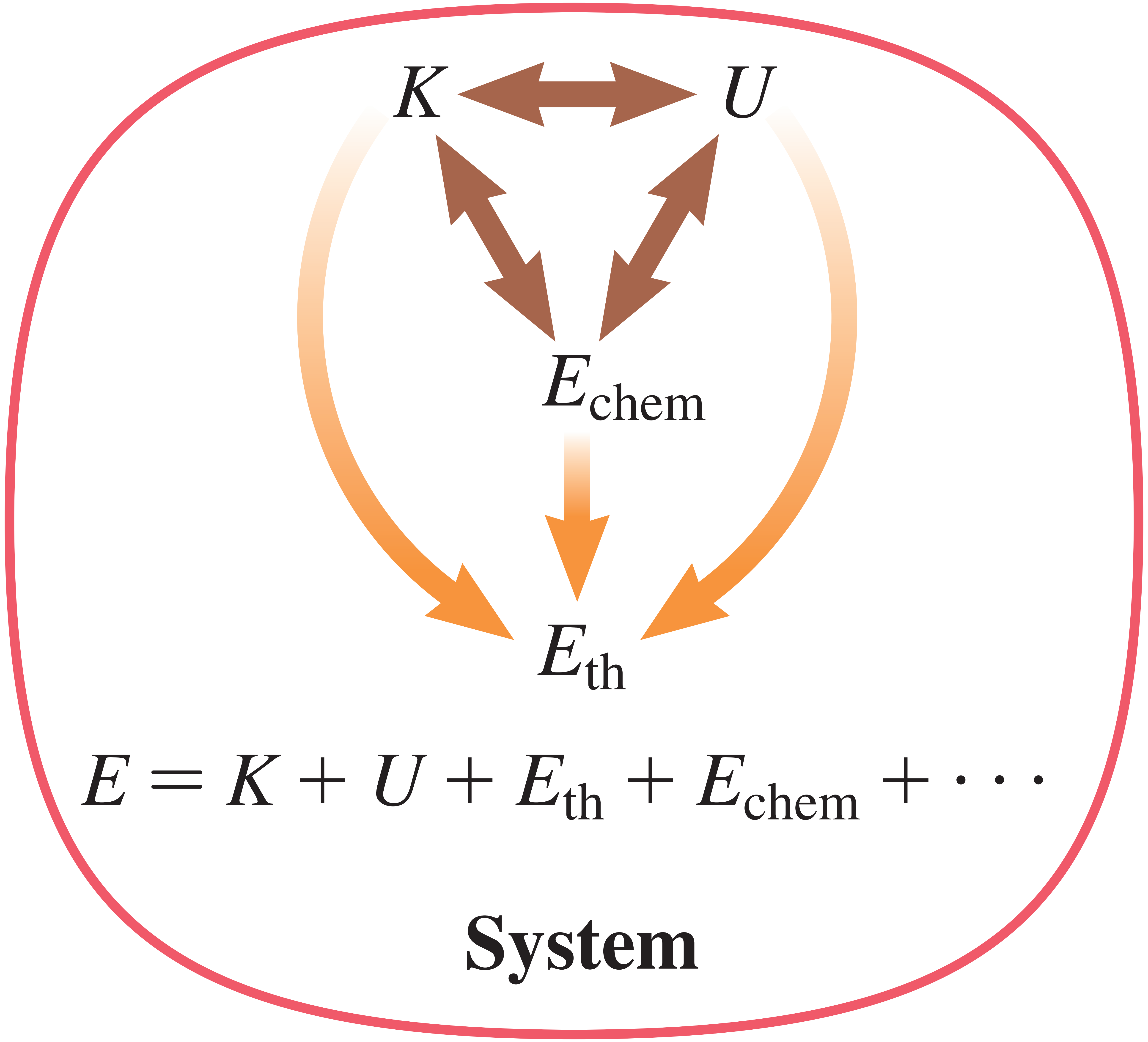
Thermal energy:

Other forms include:

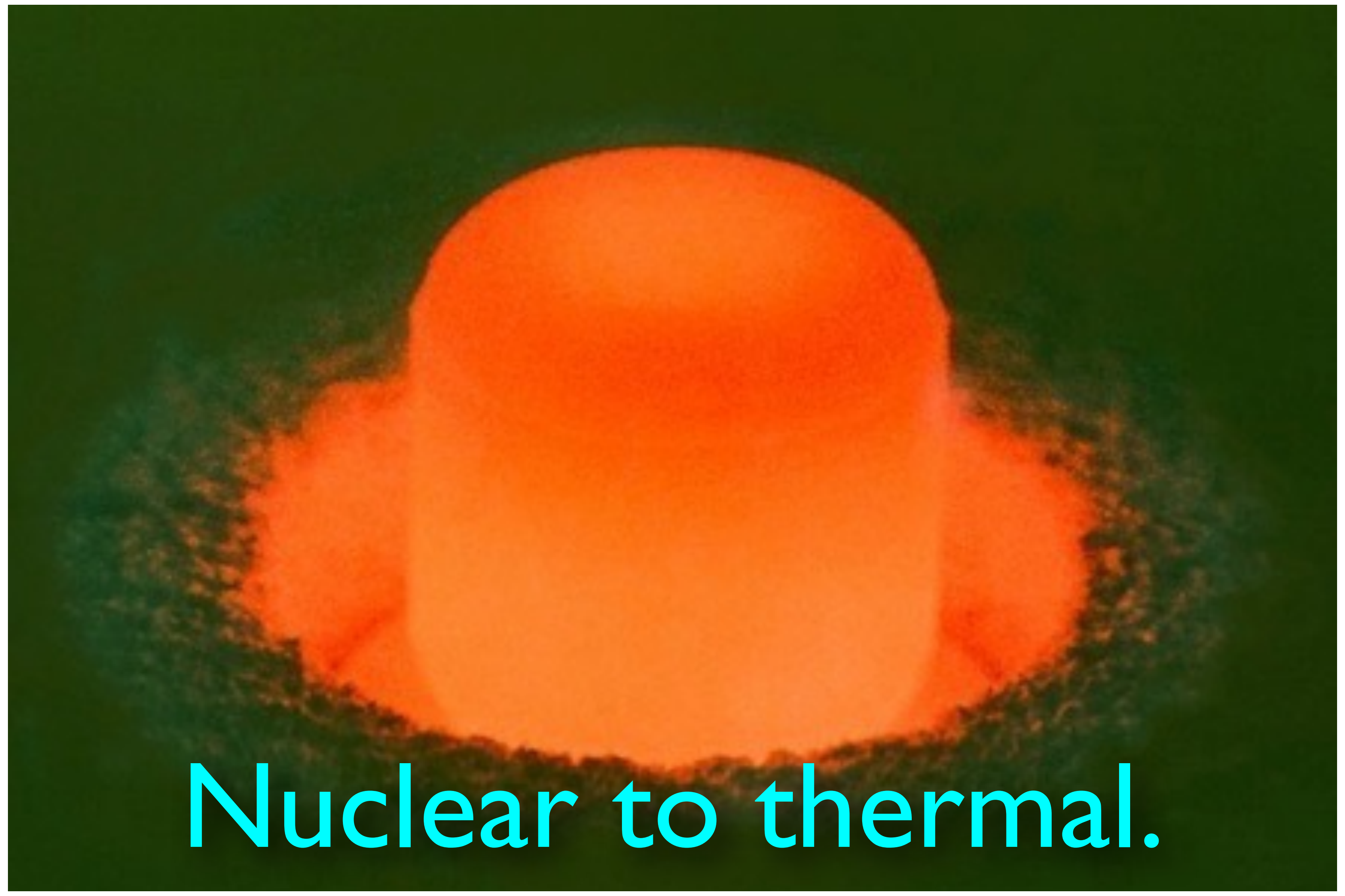
E_{chem}

$E_{nuclear}$

The Basic Energy Model



Thermal Energy is Special.



A child on a swing is motionless at the highest point of her arc.

As she swings back down to the lowest point, what energy transformation is taking place?

A  Potential to Kinetic

C  Kinetic to Potential

B  Kinetic to Thermal

D  Potential to Thermal

After a springbok leaves the ground, it rises to a height of over 2.0 meters.

On the way up, what energy transformation is taking place?

Potential to Kinetic

Kinetic to Potential

Kinetic to Thermal

Potential to Thermal

A baseball player slides into home, coming to rest right on the plate.

What energy transformation is taking place?

A

Potential to Kinetic

C

Kinetic to Potential

B

Kinetic to Thermal

D

Potential to Thermal

A skier moves down a slope at a constant speed.

What energy transformation is taking place?

A

Potential to Kinetic

C

Kinetic to Potential

B

Kinetic to Thermal

D

Potential to Thermal

Power

Transformation:

$$P = \frac{\Delta E}{\Delta t}$$

Transfer:

$$P = \frac{W}{\Delta t}$$

Useful equation:

$$P = F \cdot v$$

Unit:

J/s = W

Power is a rate...

- Same mass...
- Both reach 60 mph...

Same final kinetic energy, but
different times mean different powers.

A 70 kg human sprinter can accelerate from rest to 10 m/s in 3.0 s.

What is the specific power—the power output divided by the mass in kg?

A 70 kg human sprinter can accelerate from rest to 10 m/s in 3.0 s.

What is the specific power—the power output divided by the mass in kg?

1. What energy changes?
2. What is the magnitude of the change?
3. What is the power?
4. What is the specific power?

Power Output for Jumpers

Animal	Mass (kg)	Jump Height (m)	Jump Time (s)	Power (W)	Power/ mass (W/kg)
Human	70	1	0.57	1200	17
Impala	40	2.4	0.73	940	24
Bushbaby	0.3	2.3	0.15	45	150
Flea	0.00075	1	0.0007	11	14,000

Energy Inputs

1.0 Calorie = 1000 calorie = 4200 J = 4.2 kJ

1.0 kJ = 1000 J = 240 calorie = 0.24 Calorie

How to solve?

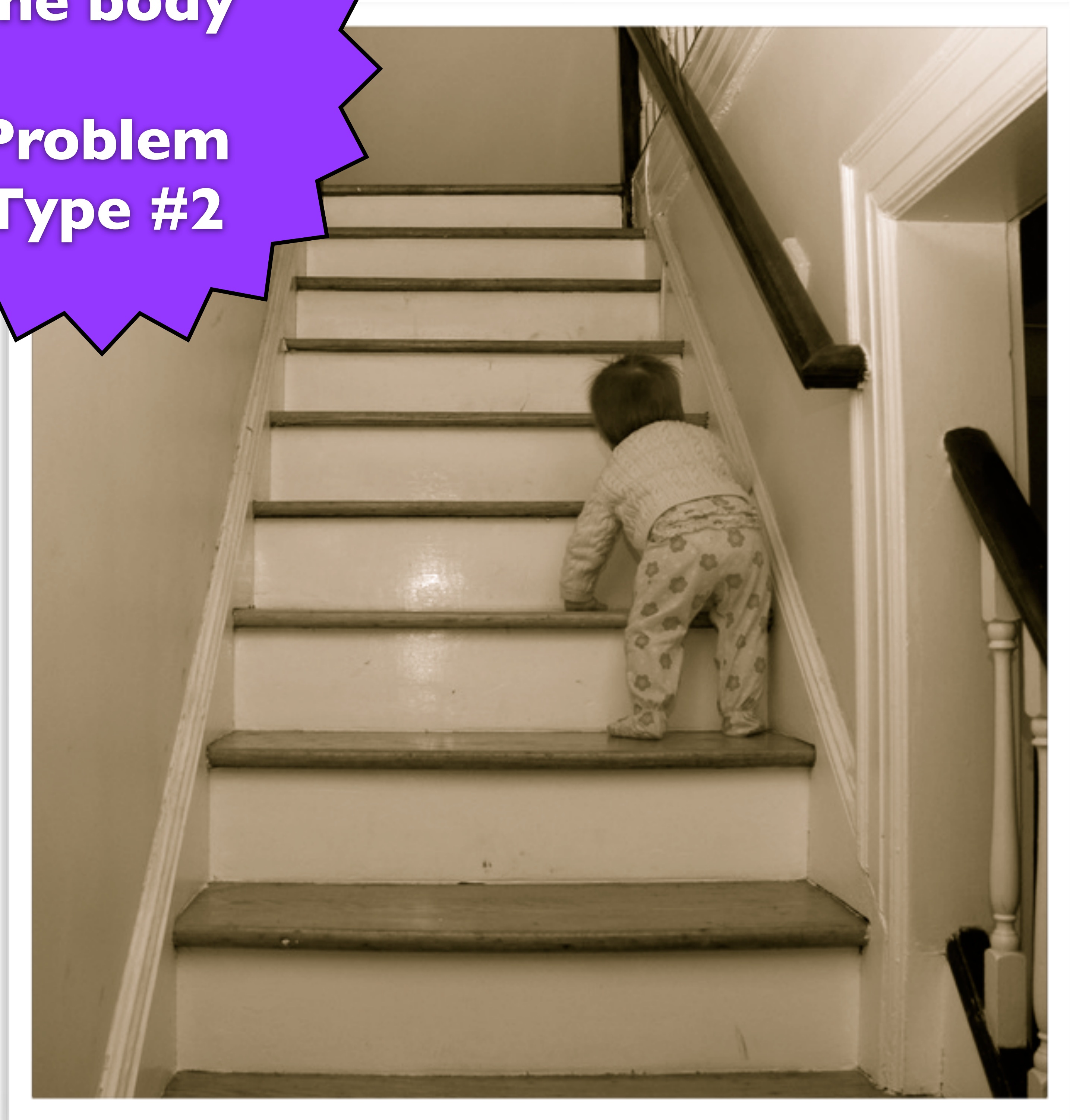
Energy in the body

Problem Type #1

Look up energy use in table.

Energy in the body

Problem Type #2



Compute energy use.

Activity	Metabolic power (W) of 68 kg individual
Typing	125
Ballroom dancing	250
Walking at 5 km/h	380
Cycling at 15 km/h	480
Swimming at a fast crawl	800
Running at 15 km/h	1150

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Energy in the body

Problem Type #1

Justin (who happens to have a mass of 68 kg) walks 10 km at a pace of 5 km/hr.

How much energy does he use?

How far could you walk on the energy in a pack of M&Ms?

Sarah (mass 68 kg) walks up a flight of stairs of height 2.7 m. What is the change in her potential energy? How much energy does her body use to complete the climb?

A 75 kg person climbs the 248 steps to the top of the Cape Hatteras lighthouse, a total climb of 59 m.

How many Little Juan bean and cheese burritos will this task require?

1.0 LJB = 240 Calorie =1000 kJ

1.0 J = 0.24 calorie

1.0 kJ = 0.24 Calorie

1.0 Calorie = 4.2 kJ

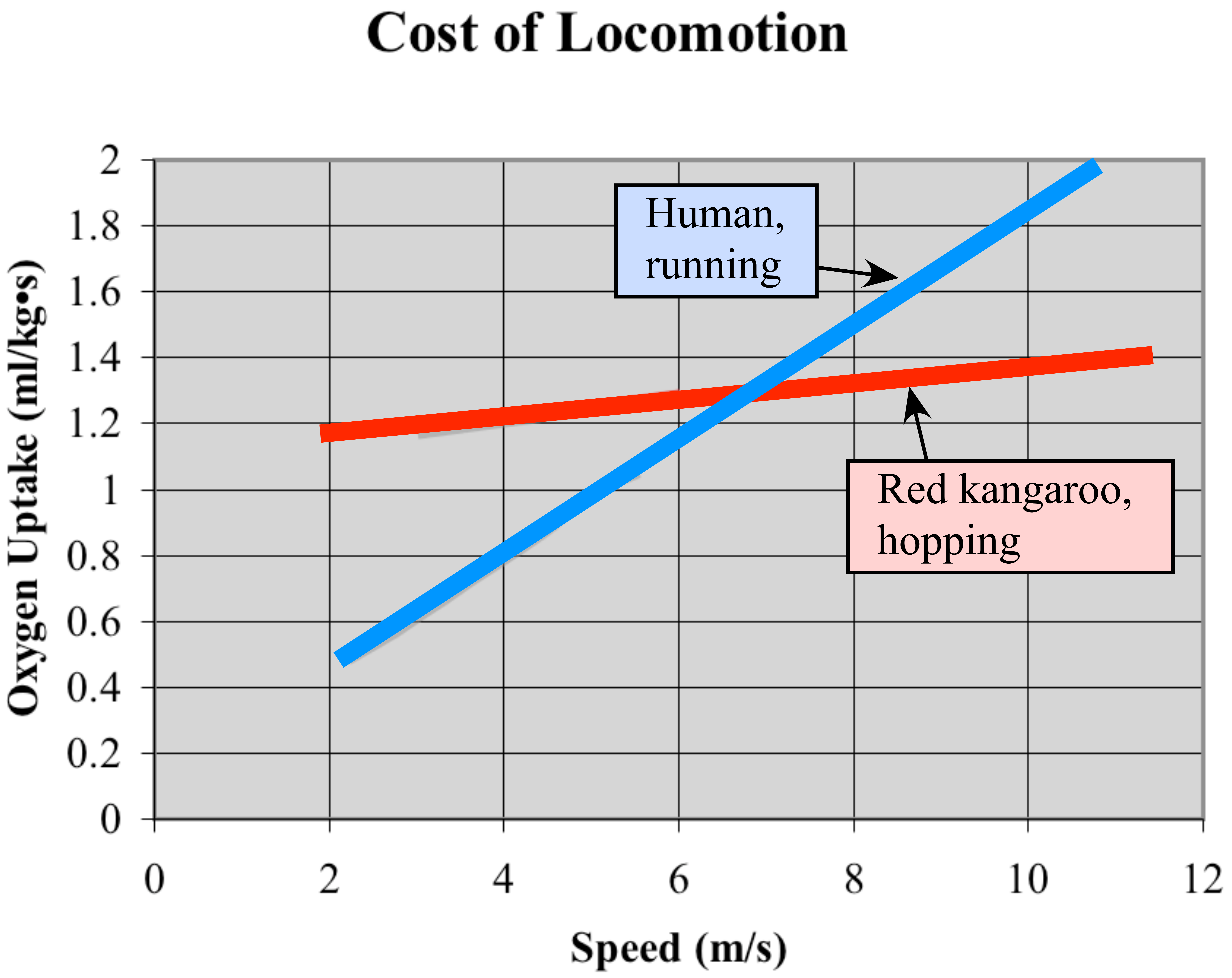
How high could you climb on the energy in one pack of fun size M&Ms?

Energy use at rest.

Energy use of the body

Organ	Resting power (W) of 68 kg individual
Liver	26
Brain	19
Heart	7
Kidneys	11
Skeletal muscle	18
Remainder of body	19
Total	**100**

About 1.5 W/kg



Cost of Locomotion
Human, running
Red kangaroo, hopping
Oxygen Uptake (ml/kg•s)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Speed (m/s)

Runner A and Runner B (who have the same mass) complete a 5.0 km course.

Runner A takes 20 minutes.
Runner B takes 40 minutes.

Who uses more energy?

Runner A

Runner B

Same

Kangaroo A and Kangaroo B (who have the same mass) complete a 5.0 km course.

Kangaroo A takes 20 minutes.

Kangaroo B takes 40 minutes.

Which uses more energy?

A  Kangaroo A

B  Kangaroo B

C  Same

The Rainbow and Beyond

Shortcut for computing photon energies:

$$E \text{ (in eV)} = \frac{1240}{\lambda \text{ (in nm)}}$$

Atomic Energies

Process	Energy
Breaking a hydrogen bond between two water molecules	0.24 eV
Energy released in metabolizing one molecule of ATP	0.32 eV
Breaking the bond between atoms in a water molecule	4.7 eV
Ionizing a hydrogen atom	13.6 eV

The Electromagnetic Spectrum

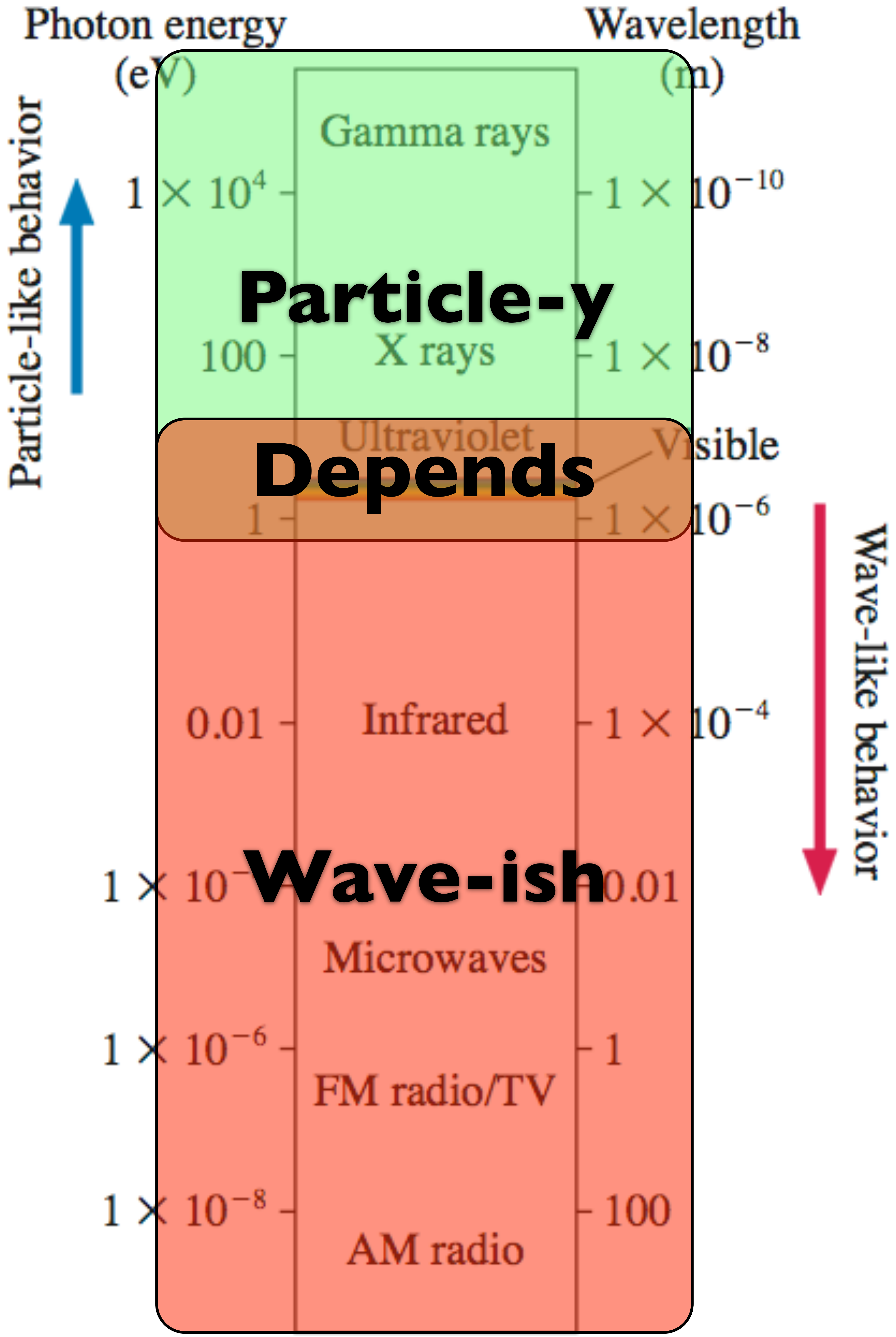
Wave	Wavelength	Frequency	Photon energy
FM Radio	3.0 m	100 MHz	0.41 μeV
Microwave	16 cm	1.9 GHz	7.9 μeV
Far IR	10,000 nm	3.0×10^{13}	0.12 eV
Near IR	1,000 nm	3.0×10^{14}	1.2 eV
Red	700 nm	4.3×10^{14}	1.8 eV
Visible (typical)	500 nm	6.0×10^{14}	2.5 eV
Blue	400 nm	7.5×10^{14}	3.1 eV
Ultraviolet	290 nm	1.0×10^{15}	3.4 eV

The Electromagnetic Spectrum

$$c = \lambda f$$

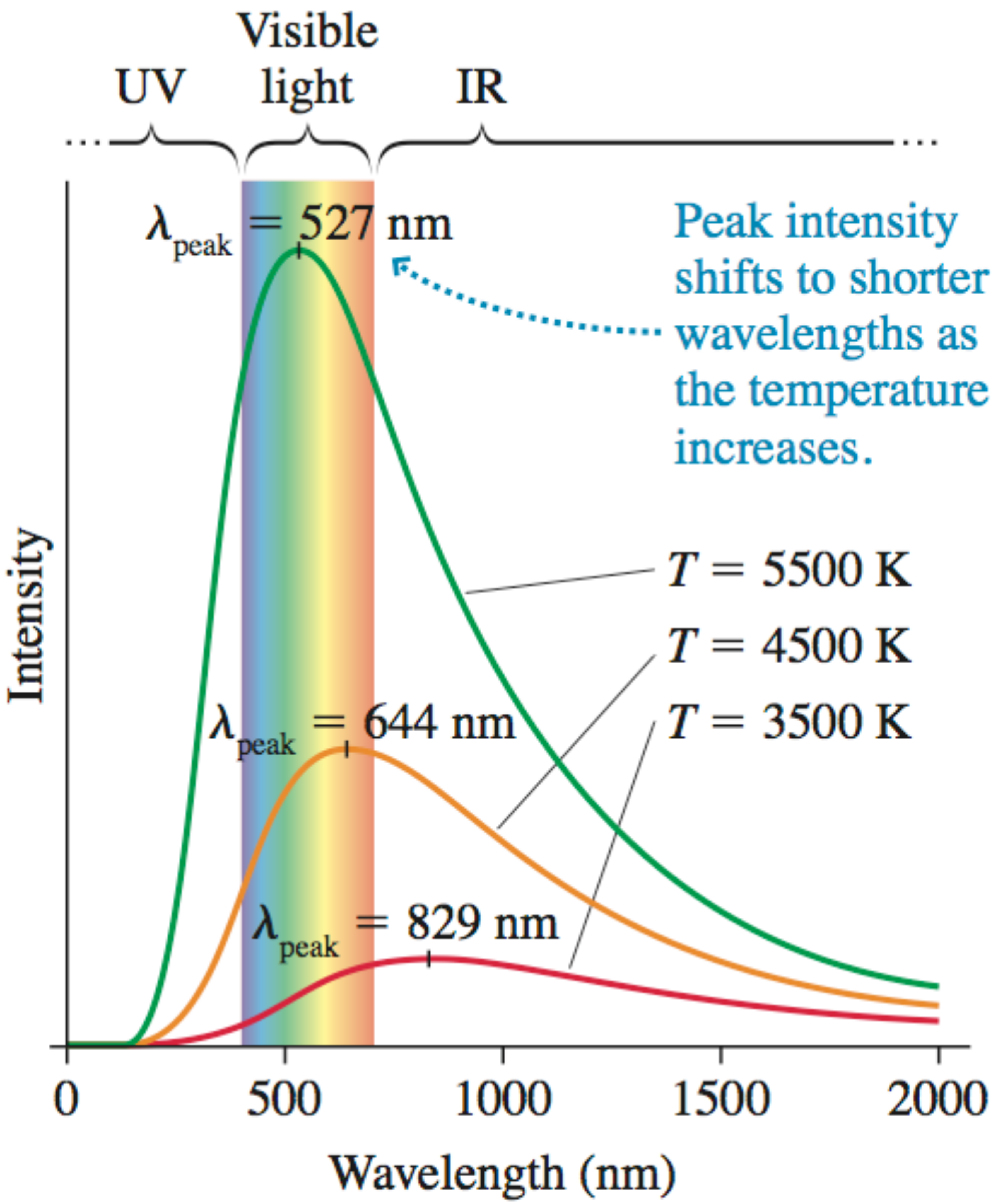
$$E_{\text{photon}} = hf$$

$$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$$



Atomic Radiation

Wavelength varies with temperature.



$$\lambda_{peak}\,(\text{in nm}) = \frac{2.9 \times 10^6\ \text{nm} \cdot \text{K}}{T} \qquad (25.22)$$

Wien's law for the peak wavelength of a thermal emission spectrum

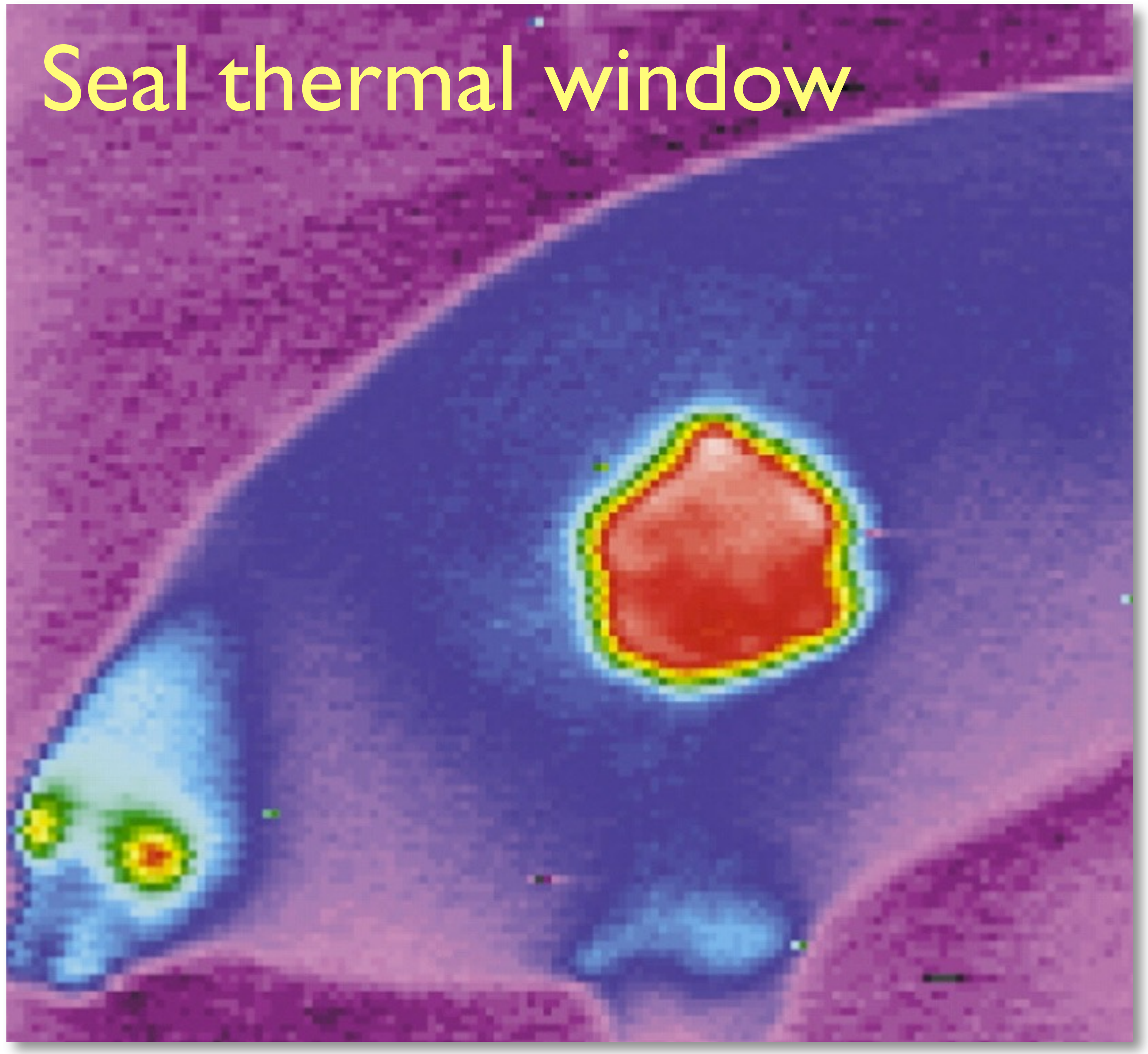
Emitting EM Waves Means Emitting Energy

$$\frac{Q}{\Delta t} = e\sigma A T^4$$

Rate of heat transfer by radiation at temperature T

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}$$

From Chapter 12



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Wien's law for the peak wavelength of a thermal emission spectrum

$$\frac{Q}{\Delta t} = e\sigma A T^4$$

Rate of heat transfer by radiation at temperature T (Stefan's Law)

You Look Positively Radiant

A typical human has a surface area of about 1.8 m². All skin, regardless of color, has an emissivity of about e=0.97.

How much power does a person's body radiate at normal skin temperature? (About 33 °C, or 306 K)

What is the peak wavelength of the emission?

870 W

9500 nm