Energy of a System

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We can also do WORK on a system, as a way of putting energy into the system

Energy of a System

We can also do WORK on a system, as a way of putting energy into the system

Or the system can do work, which takes energy out of the system

Change in energy content

Energy transferred as work to or from the system

$$\Delta U = q + w$$

Positive value:
energy INTO the system

Energy transferred as heat to or from the system

Work (at constant pressure)

Change in volume

$$w = -P \times \Delta V$$

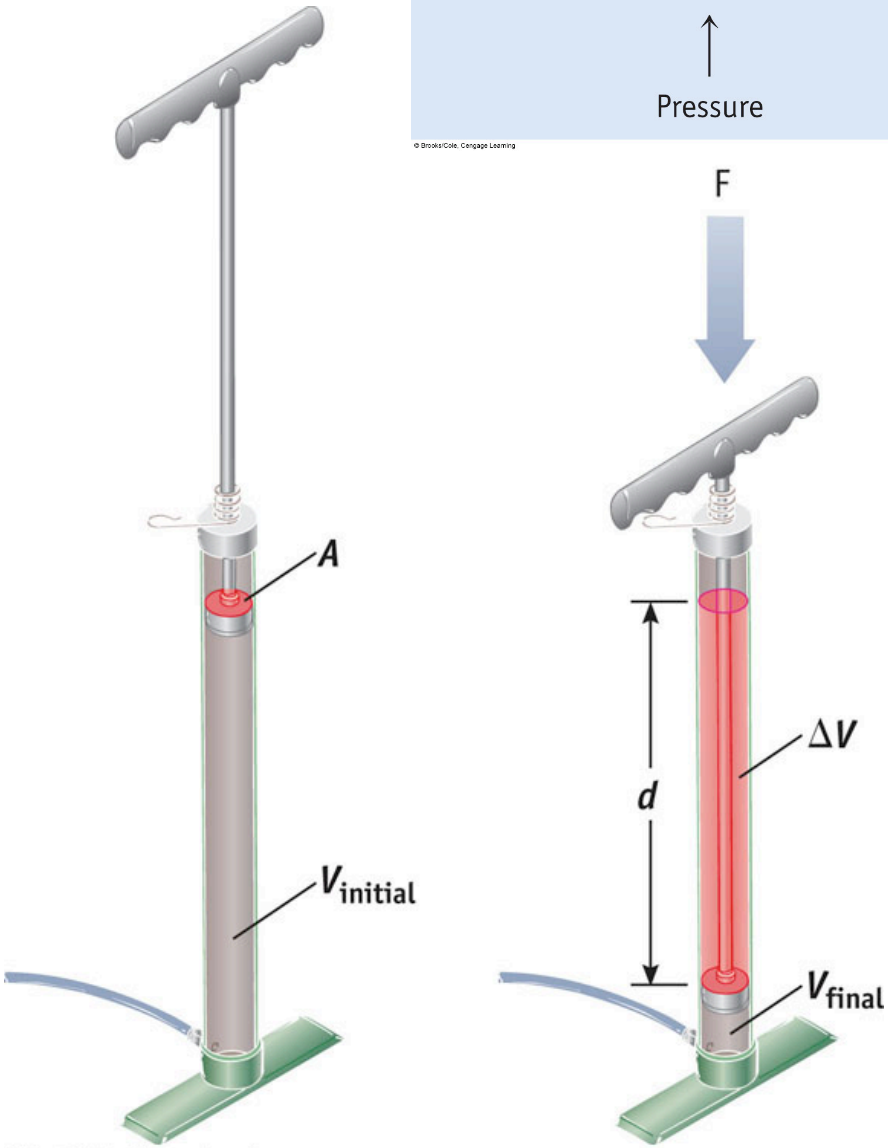
Pressure

Work (at constant pressure)

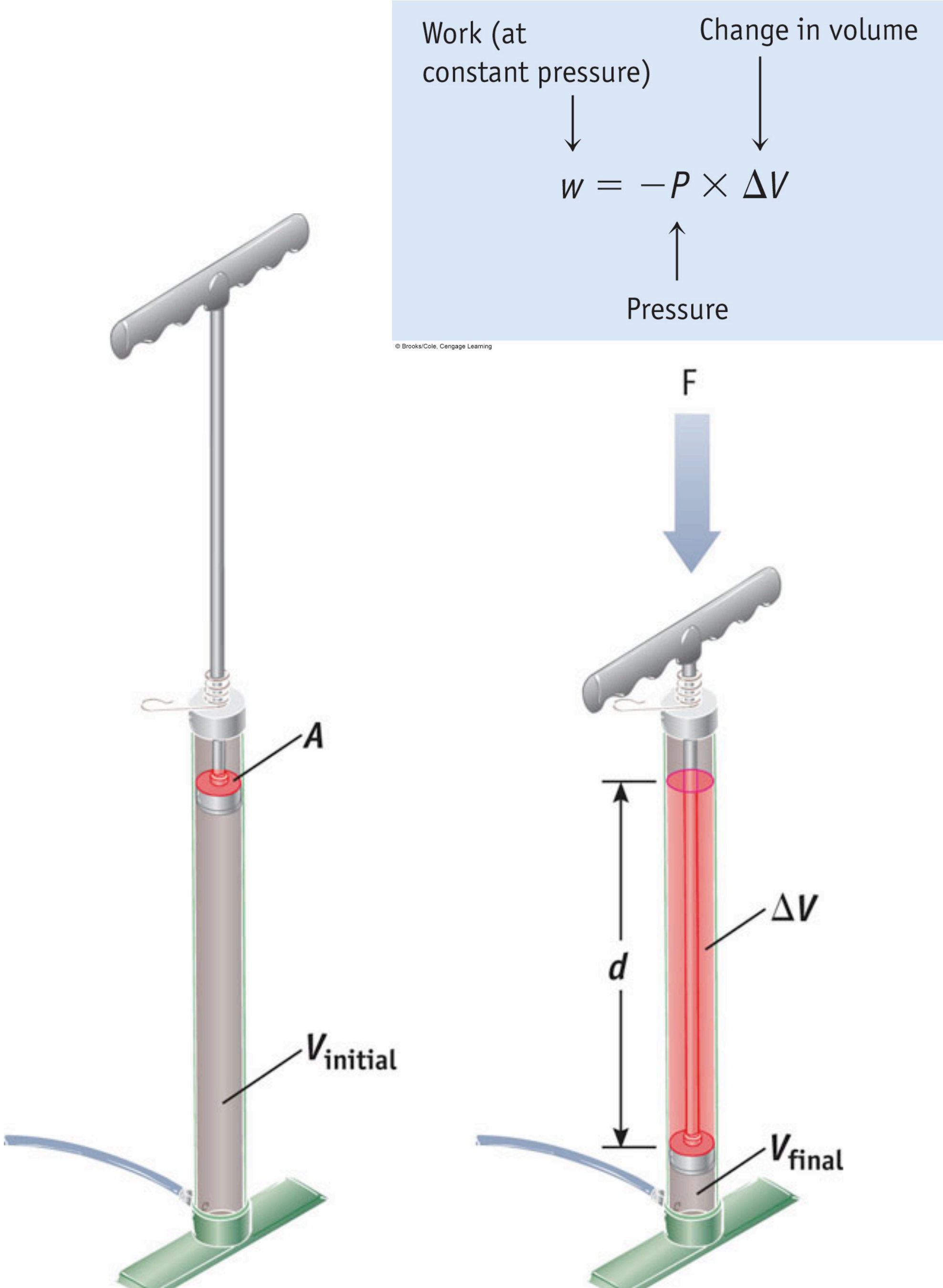
Change in volume

$$w = -P \times \Delta V$$

Pressure



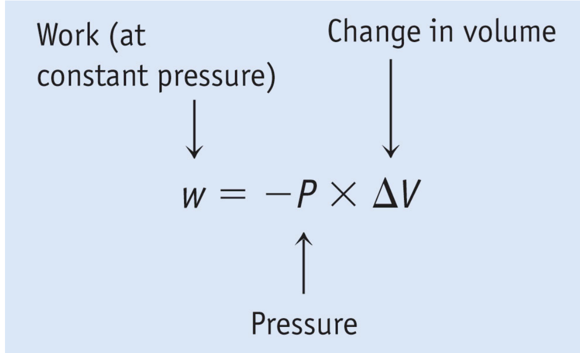
A Closer Look, p. 225



$$w = -P\left(V_{final} - V_{initial}\right)$$

$$w = -(1\ atm)(0.1L - 0.5L) = +0.4\ atm \cdot L$$

A Closer Look, p. 225



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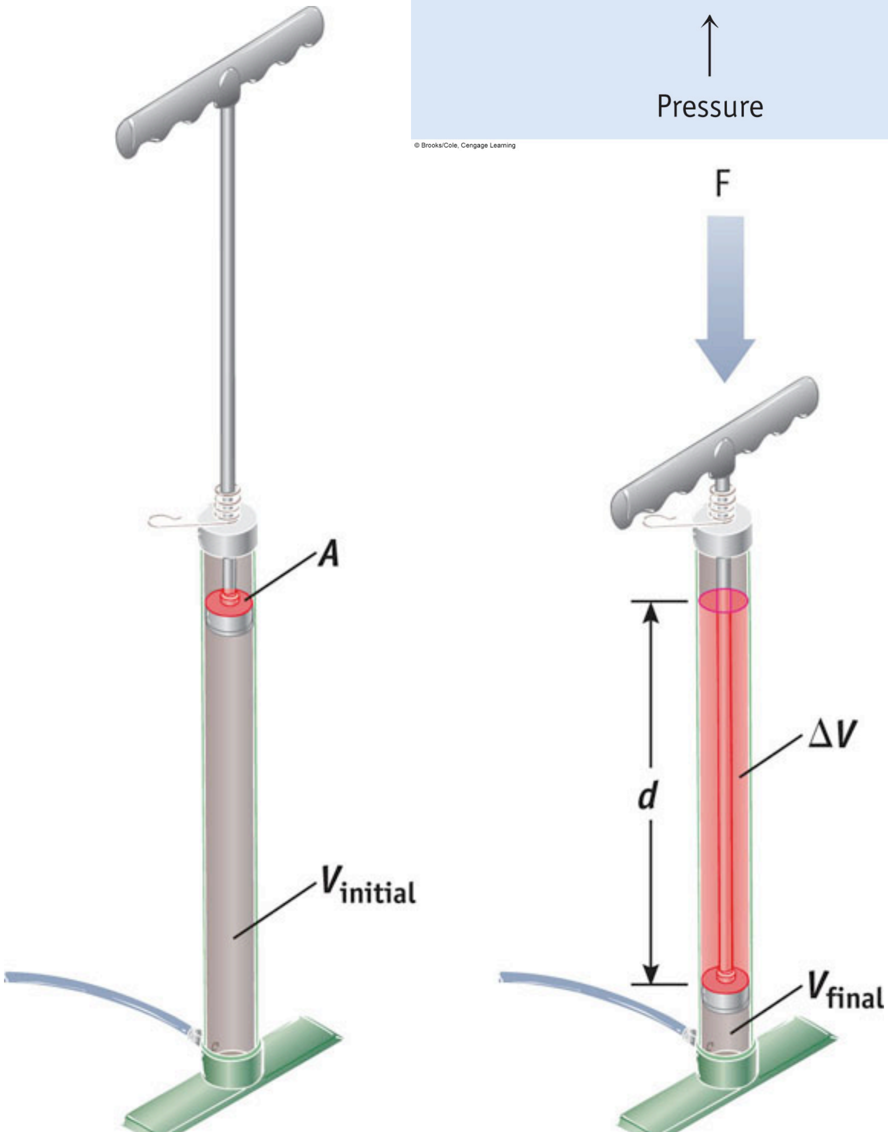
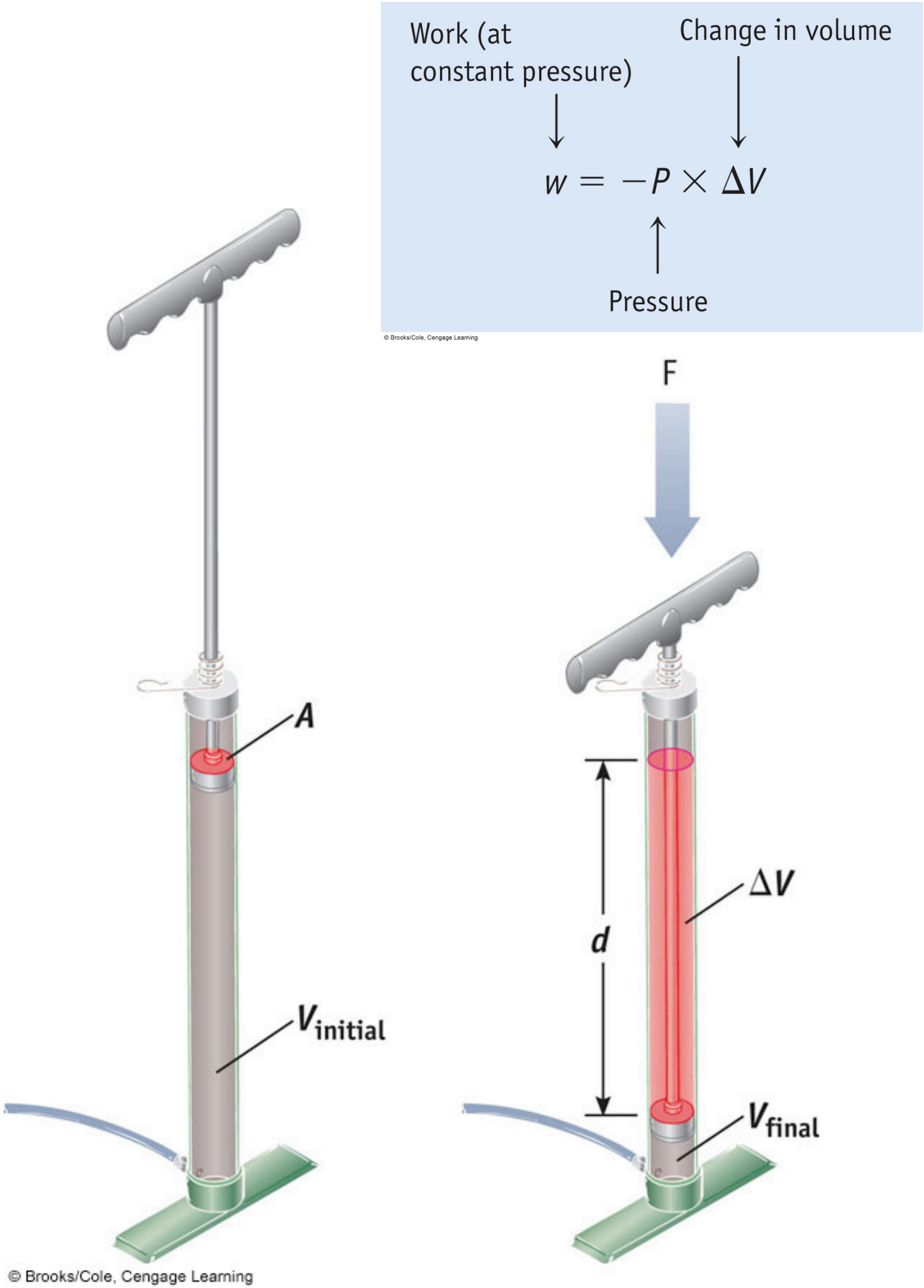
Work is positive.
Work is done ON system
Energy of system increases



A Closer Look, p. 225



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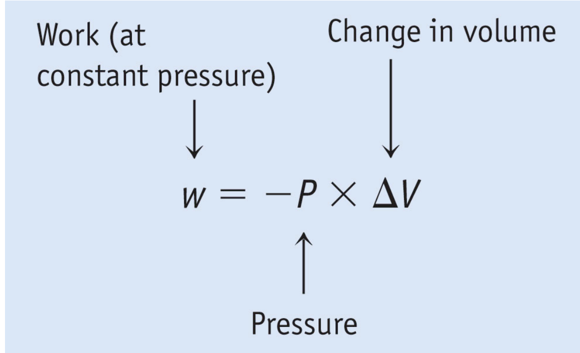

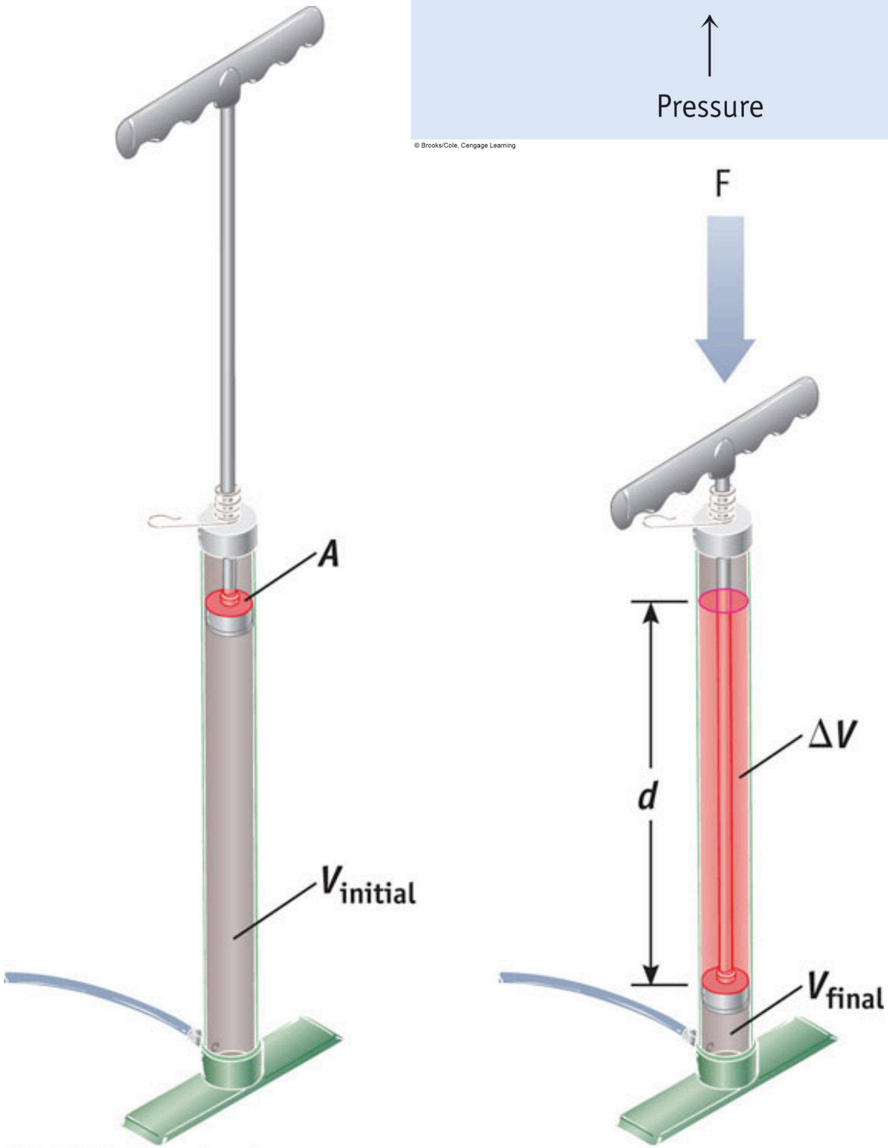

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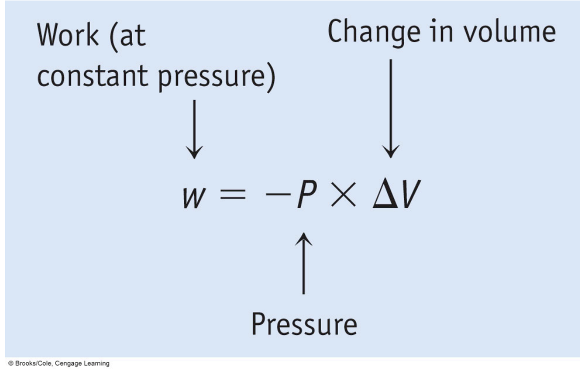
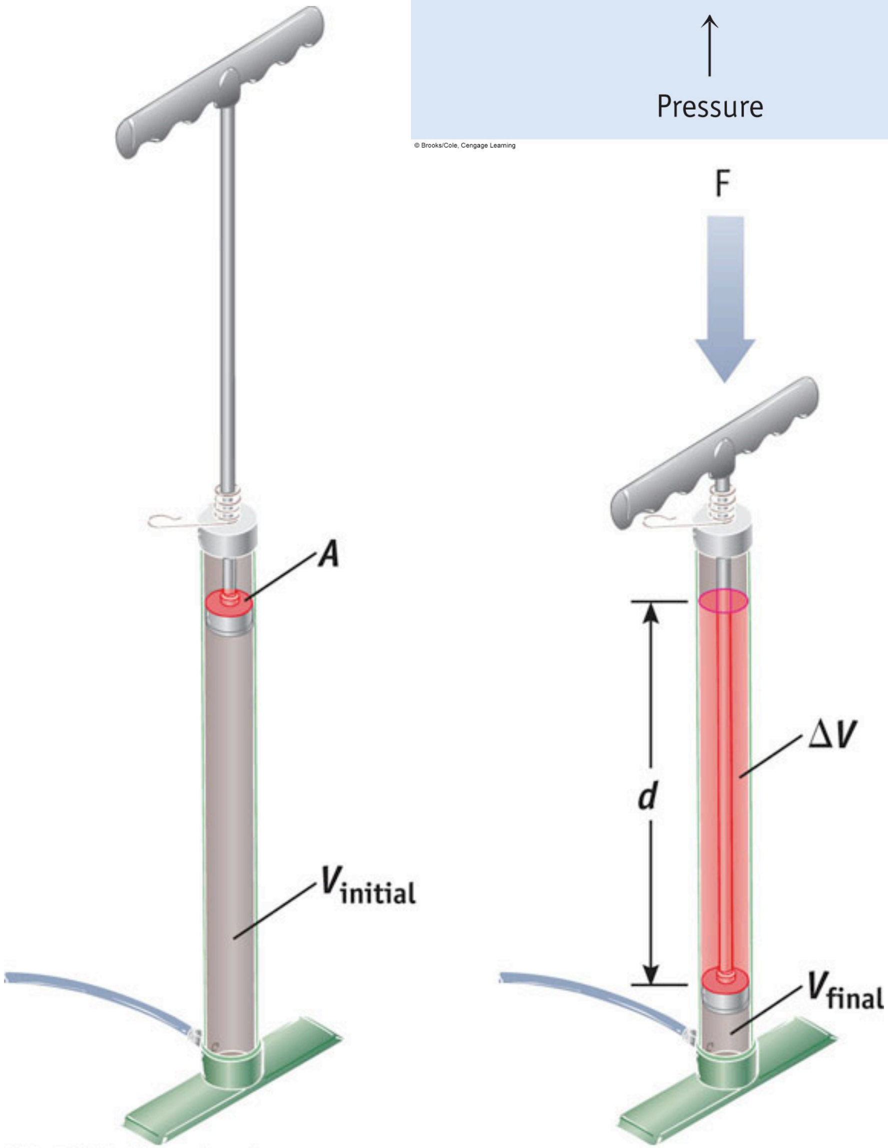
From inside back of book

$$R = 8.3144 \frac{J}{K \cdot mol} \qquad R = 0.082057 \frac{L \cdot atm}{K \cdot mol}$$

A Closer Look, p. 225





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Therefore:

A Closer Look, p. 225

Work (at constant pressure) | Change in volume | Pressure

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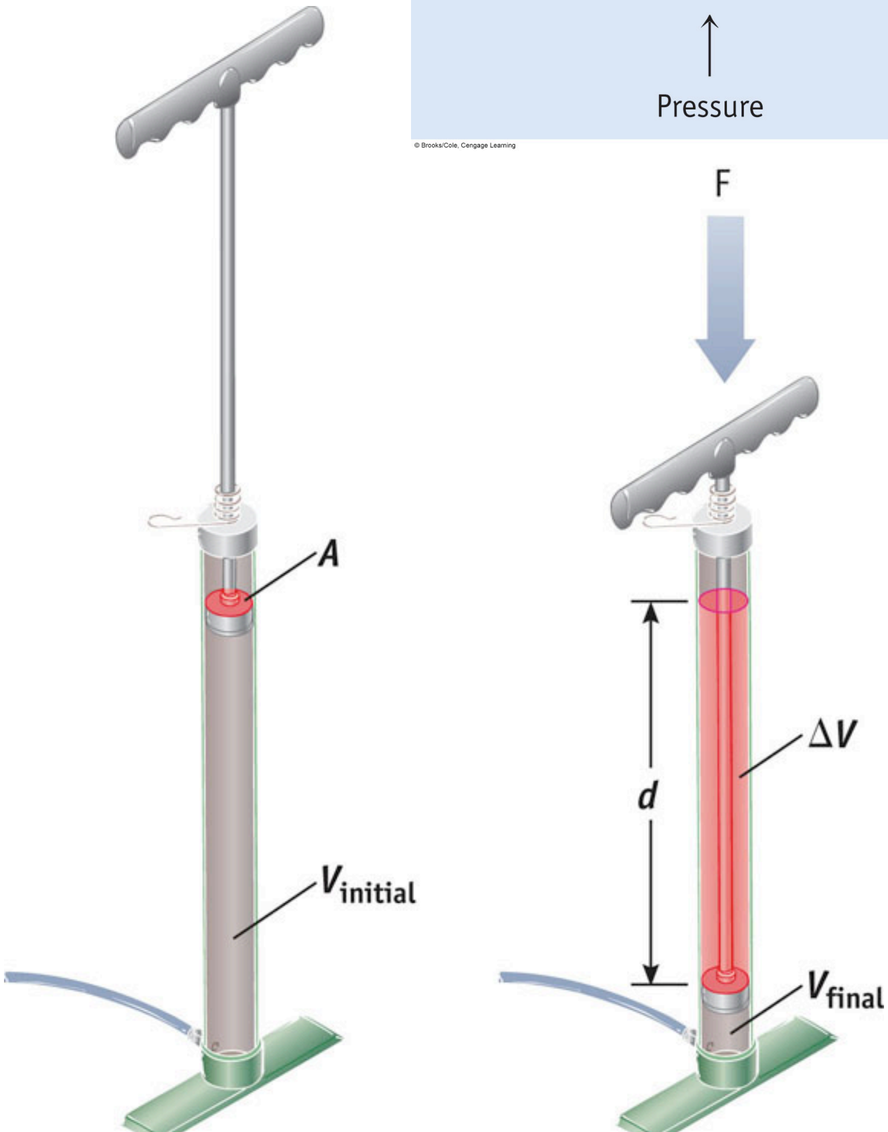

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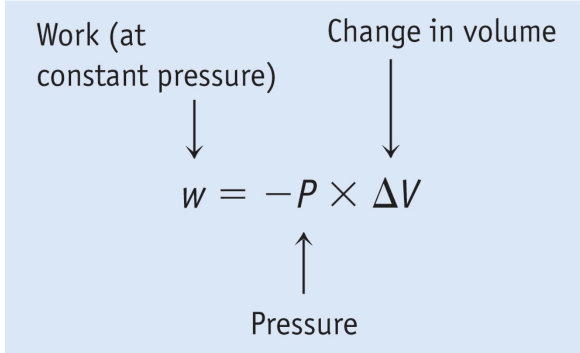
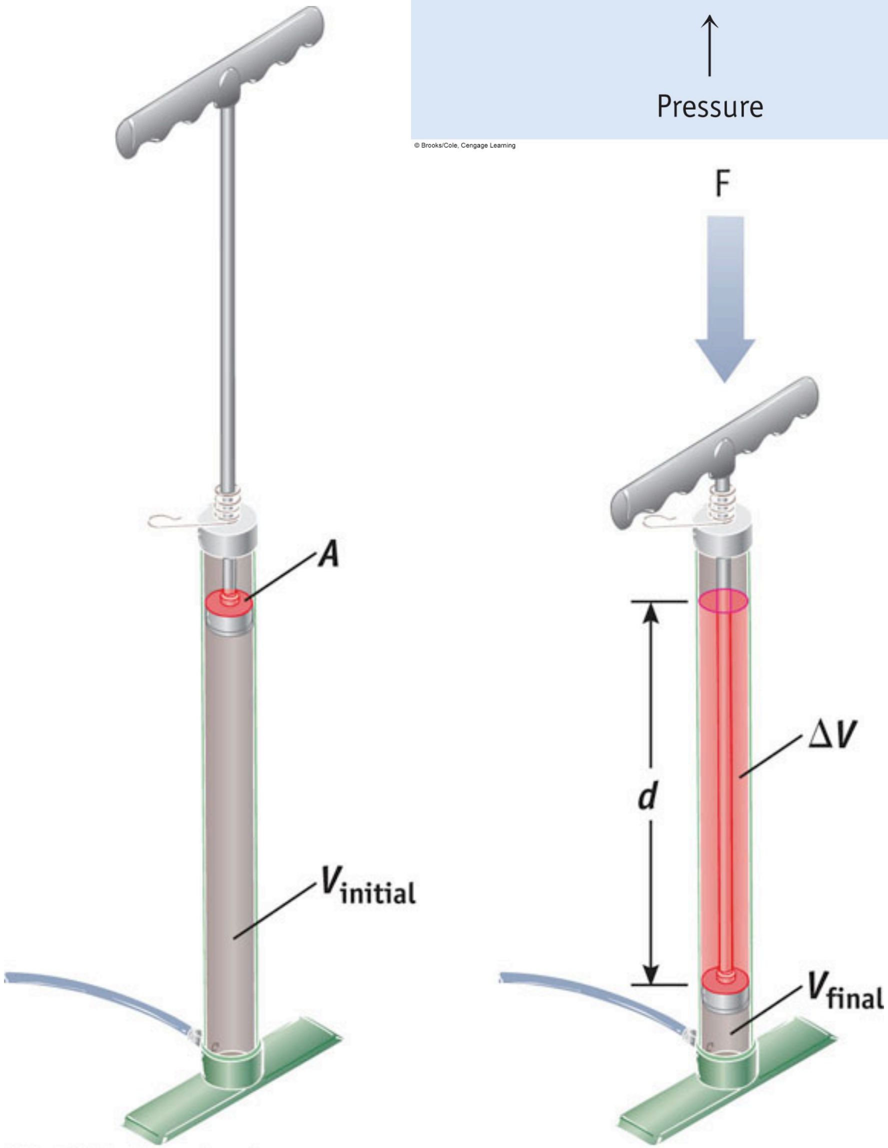
$$L \cdot atm = 101.32\ J$$

A Closer Look, p. 225





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$$L \cdot atm = 101.32\ J$$

$$w = +0.4\ atm \cdot L\left(\frac{101.32\ J}{atm \cdot L}\right) = 40.53\ J$$

A Closer Look, p. 225

q and w

q and w

Energy transferred as heat to system (endothermic) $q>0$

q and w

Energy transferred as heat to system (endothermic) $q>0$

Energy transferred as heat from system (exothermic) $q<0$

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Energy transferred as heat from system (exothermic) $q<0$

Energy transferred as work done on system $w>0$

q and w

Energy transferred as heat to system (endothermic)	$q>0$
Energy transferred as heat from system (exothermic)	$q<0$
Energy transferred as work done on system	$w>0$
Energy transferred as word done by system	$w<0$

q and w

		System internal energy
Energy transferred as heat to system (endothermic)	$q>0$	
Energy transferred as heat from system (exothermic)	$q<0$	
Energy transferred as work done on system		$w>0$
Energy transferred as word done by system		$w<0$

q and w

		System internal energy
Energy transferred as heat to system (endothermic)	$q>0$	$U \uparrow$
Energy transferred as heat from system (exothermic)	$q<0$	
Energy transferred as work done on system		$w>0$
Energy transferred as word done by system		$w<0$

q and w

		System internal energy
Energy transferred as heat to system (endothermic)	$q>0$	U ↑
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ΔH - enthalpy

Assume reaction at constant pressure

ΔH - enthalpy

Assume reaction at constant pressure

$$\Delta U = q_p + w_p$$

$$\Delta U = q_p - P\Delta V$$

$$\therefore \quad q_p = \Delta U + P\Delta V$$

$$\text{Define}: \; H = U + PV$$

$$\therefore \; \Delta H = \Delta U + P\Delta V$$

$$\therefore \; \Delta H = q_p$$

ΔH - enthalpy

Assume reaction at constant pressure

$$\Delta U = q_p + w_p$$

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Bottom line:
almost all of biology occurs at 1 atm pressure (constant)

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Bottom line:
almost all of biology occurs at 1 atm pressure (constant)

ΔH is a useful measure of the change in energy of a system

$$\text{Define}: \; H = U + PV$$

$$\therefore \; \Delta H = \Delta U + P\Delta V$$

$$\therefore \; \Delta H = q_p$$

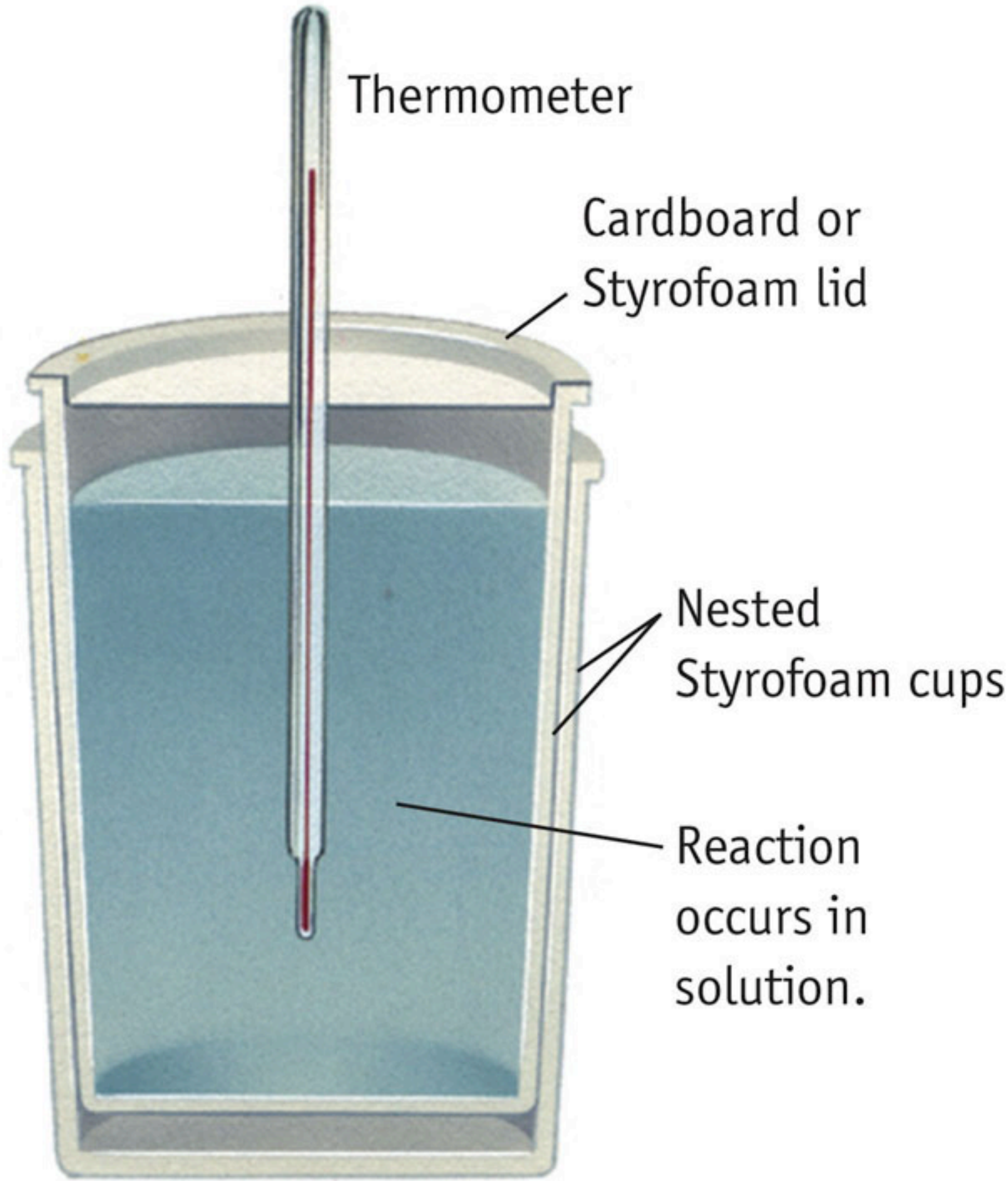
Thermometer
Cardboard or
Styrofoam lid
Nested
Styrofoam cups
Reaction
occurs in
solution.

Fig. 5-14, p. 230

Energy is a **State Function**

A state function defines a system independent of “how you got there”

State Functions:

- Energy (ΔU, ΔH)
- Pressure
- Volume
- Temperature
- Elevation
- Your bank balance

NOT State Functions:

- Driving distance to Boston
- q
- w

Enthalpy (ΔH) of a reaction

$H_2O\ (g) \longrightarrow H_2\ (g) + \frac{1}{2} O_2\ (g)$ $\Delta H° = +241.8$ kJ/mole-rxn

What does this tell us?

$\Delta H > 0$ endothermic.

Have to put **energy in** **(heat)** to make the reaction go to the right as written

241.8 per mole as written (per 1 H_20 consumed, or per 1 H_2 produced)

Enthalpy (ΔH) of a reaction

$\Delta H° = +241.8$ kJ/mole-rxn

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What is $\Delta H°$ for

$2H_2O\ (g) \longrightarrow 2H_2\ (g) + O_2\ (g)$

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$2H_2O\ (g) \longrightarrow 2H_2\ (g) + O_2\ (g)$	$\Delta H° = +2(241.8$ kJ/mole-rxn$)$
	$\Delta H° = +483.6$ kJ/mole-rxn

Chemical Equation Accounting/Math

$C\ (s) + O_2\ (g) \longrightarrow CO\ (g) + \frac{1}{2}\ O_2\ (g)$ $\Delta H° = -110.5$ kJ/mol

$CO\ (g) + \frac{1}{2}\ O_2\ (g) \longrightarrow CO_2\ (g)$ $\Delta H° = -283.0$ kJ/mol

$C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g)$ $\Delta H° =$?? kJ/mol

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$C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g)$ $\Delta H° = -393.5$ kJ/mol

Chemical Equation Accounting/Math

$C\ (s) + O_2\ (g) \longrightarrow \cancel{CO}\ (g) + \frac{1}{2}\ O_2\ (g)$ $\Delta H° = -110.5\ kJ/mol$

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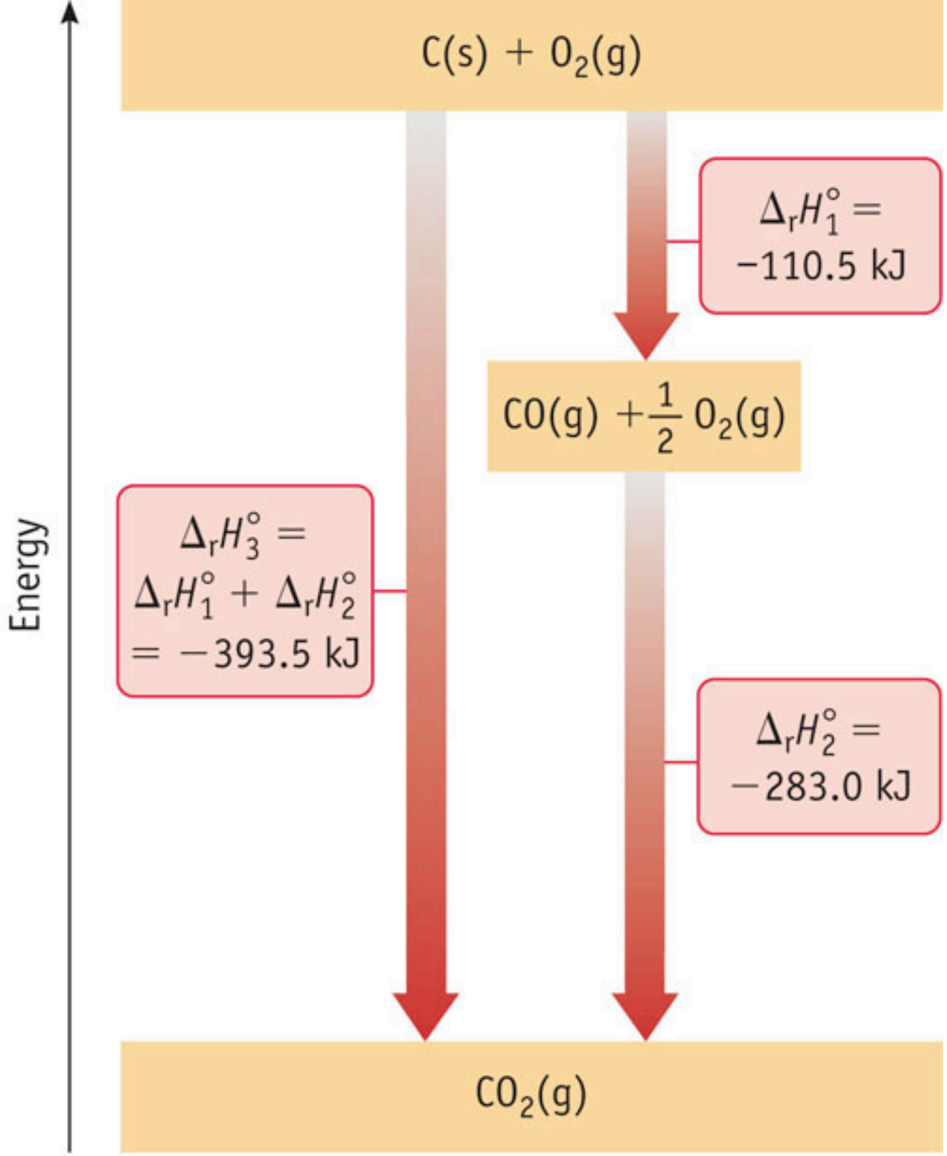

(a) The formation of CO_2 can occur in a single step or in a succession of steps. $\Delta_r H°$ for the overall process is −393.5 kJ, no matter which path is followed.

$$C\ (s) + O_2\ (g) \longrightarrow \cancel{CO}\ (g) + \tfrac{1}{2}\cancel{O_2}\ (g) \qquad \Delta H° = -110.5\ \text{kJ/mol}$$

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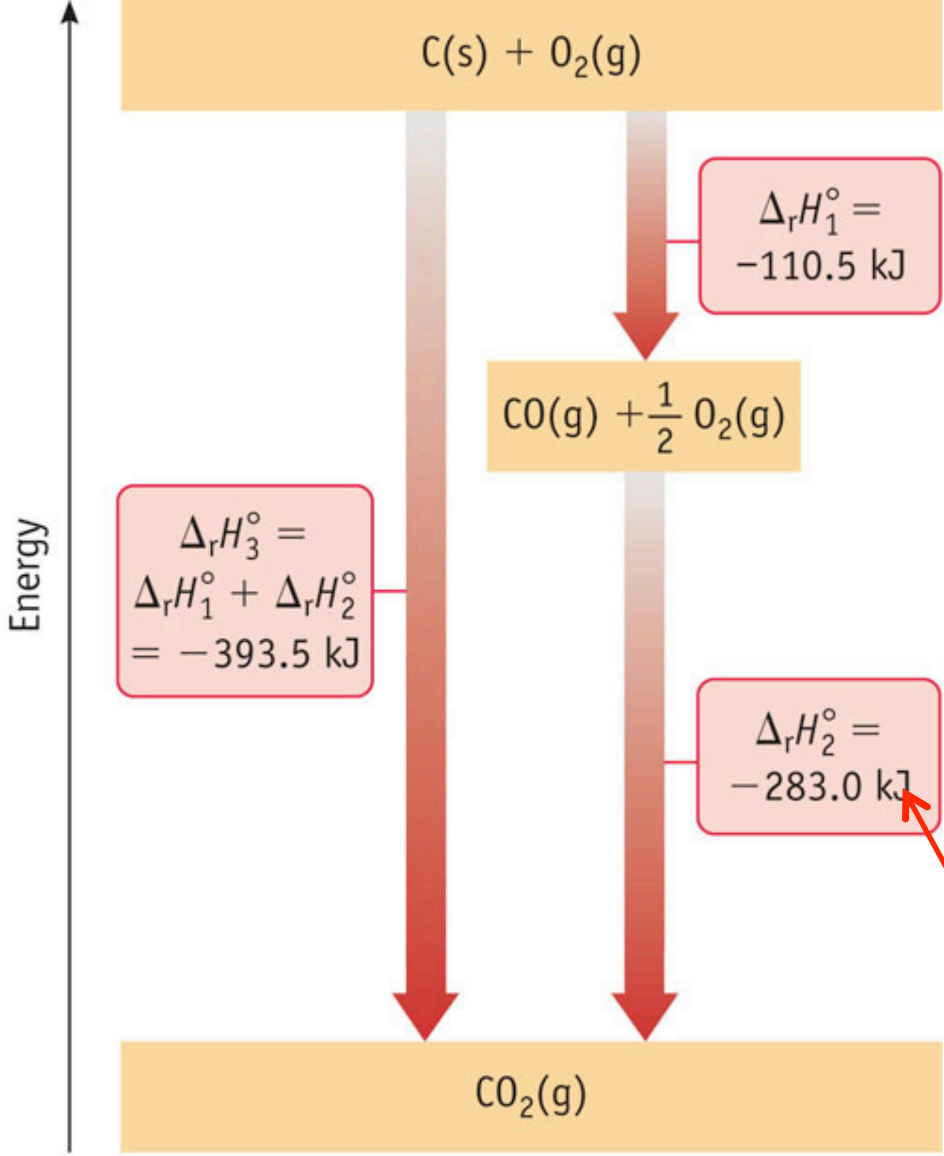
$$C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g) \qquad \Delta H° = -393.5\ \text{kJ/mol}$$

Fig. 5-16, p. 234



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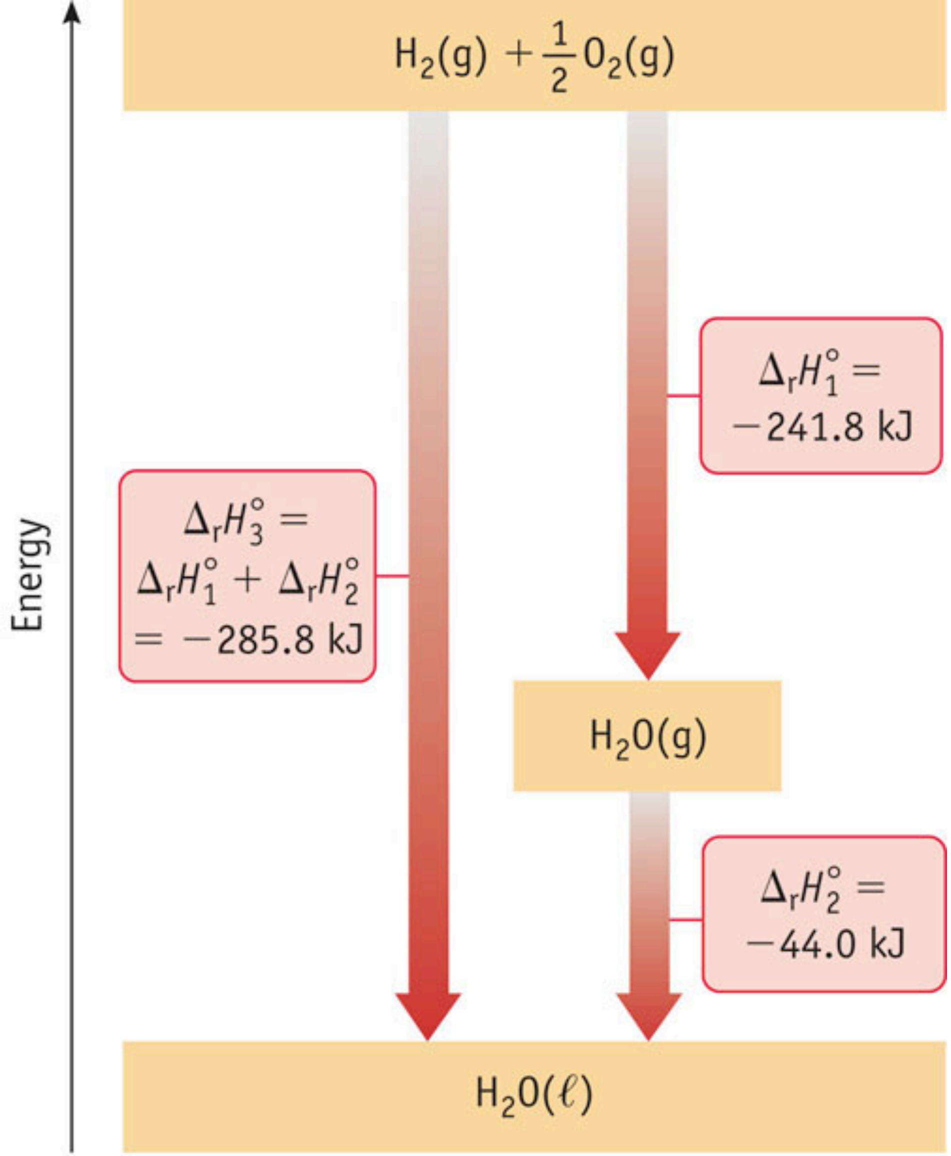
\hline
C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g) & \Delta H° = -393.5\ \text{kJ/mol}
\end{array}
$$

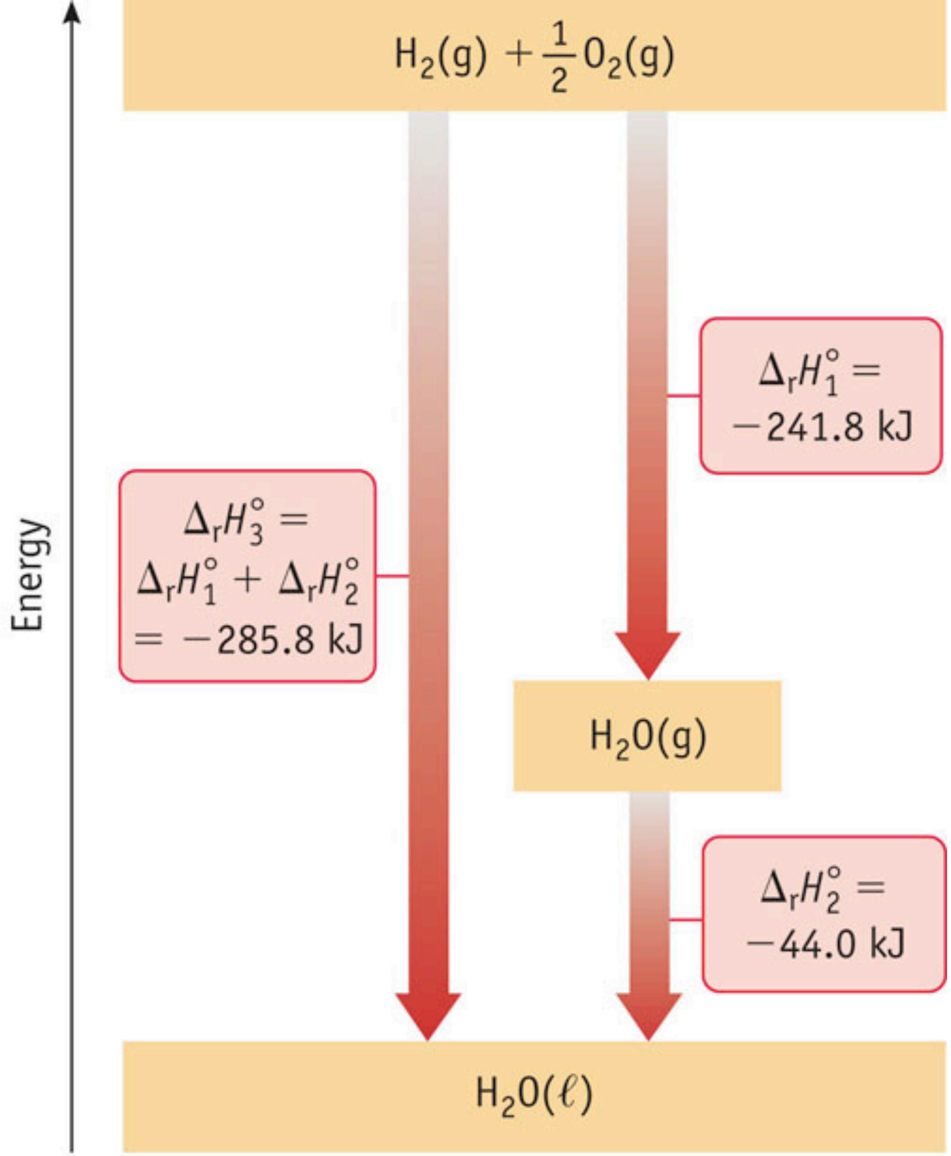
Note: convention assumes "*per mol*" (of rxn as written)

Fig. 5-16, p. 234



(b) The formation of $H_2O(\ell)$ can occur in a single step or in a succession of steps. $\Delta_r H^\circ$ for the overall process is -285.8 kJ, no matter which path is followed.

Fig. 5-16, p. 234



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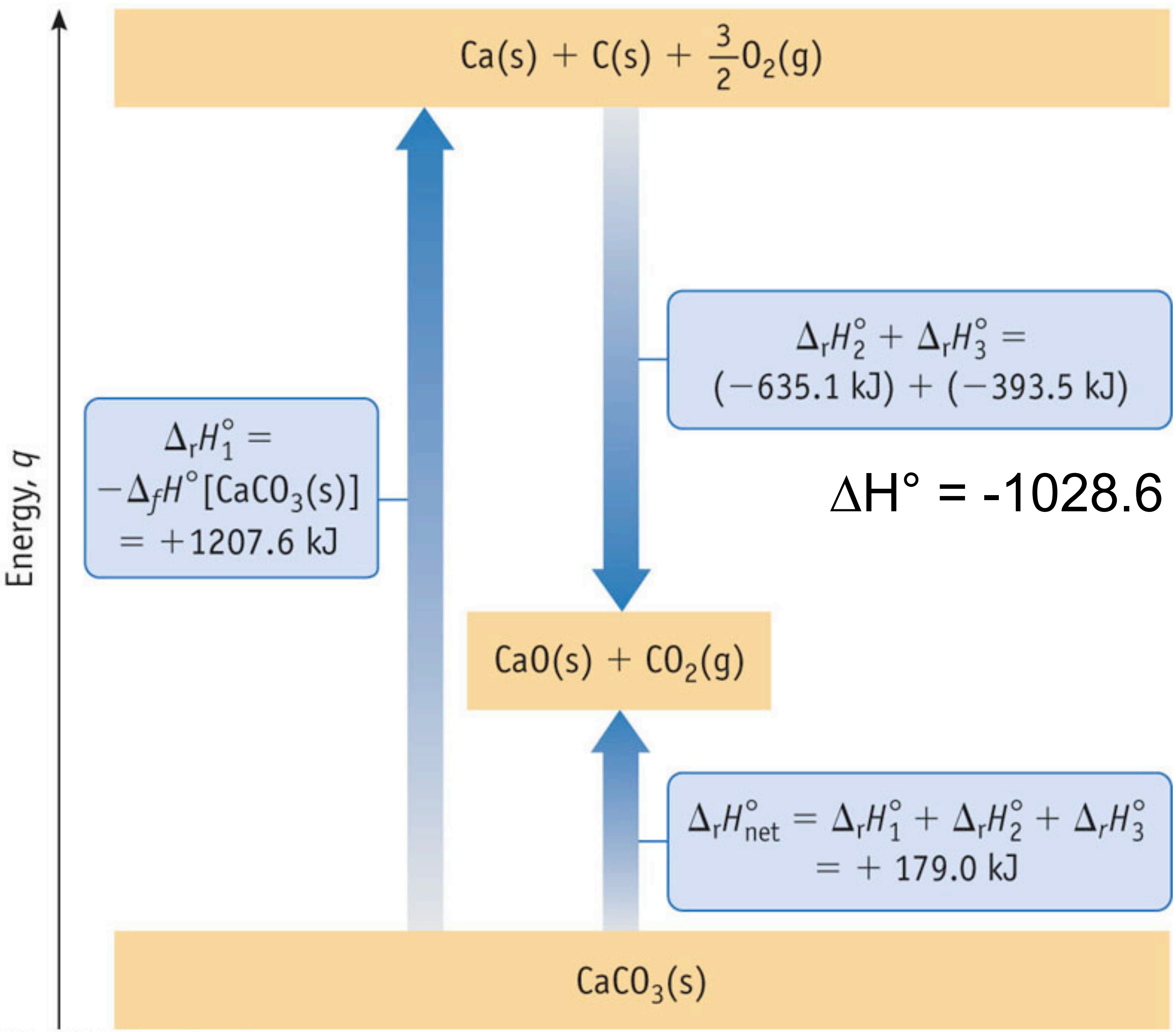
Phase Change!

Fig. 5-16, p. 234

Energy level diagram for the decomposition of $CaCO_3(s)$



$\Delta H^\circ = -1028.6\ kJ$

A Closer Look, p. 238

Math Gymnastics: What's it Good For?

$\Delta H°_f$

Math Gymnastics: What's it Good For?

Standard enthalpies of formation

Appendix L – page A29

$\Delta H°_f$

Math Gymnastics: What's it Good For?

Standard enthalpies of formation

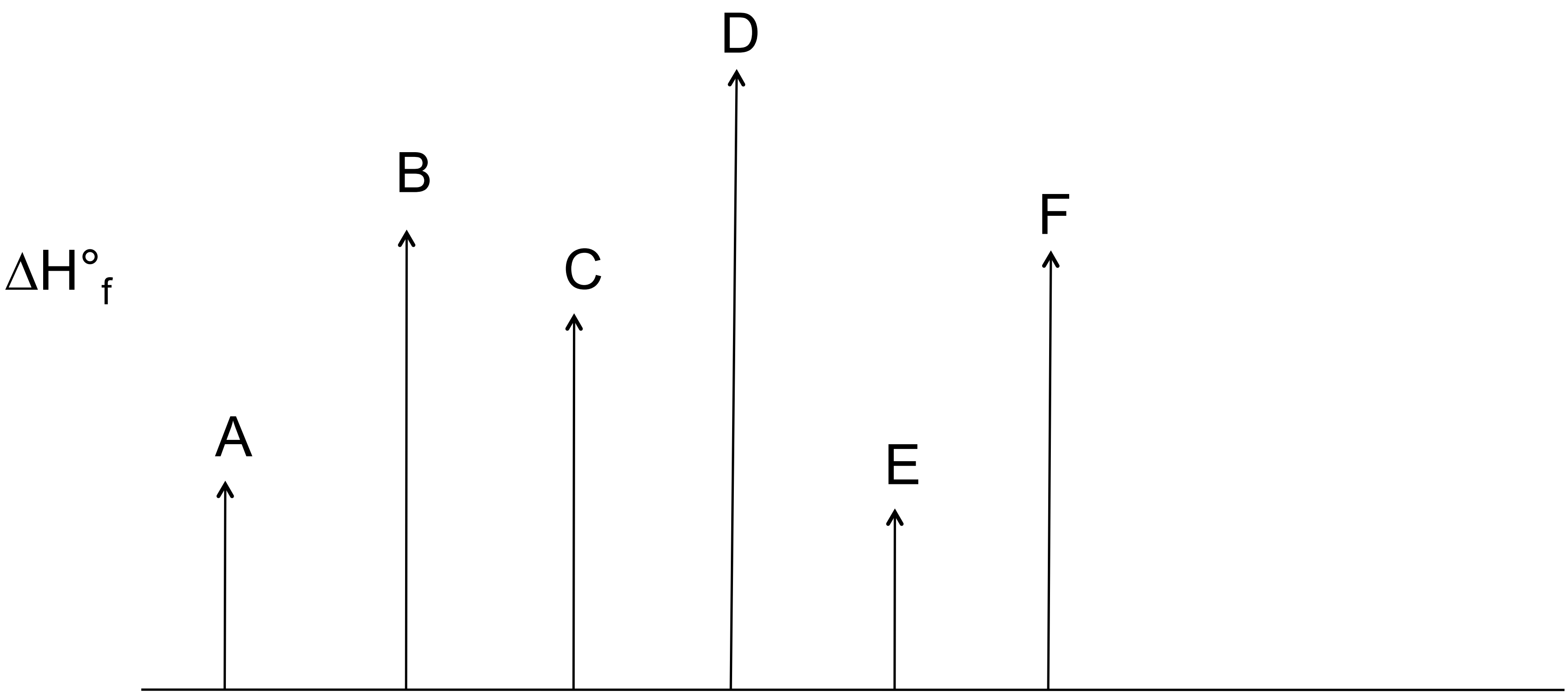
Appendix L – page A29

ΔH°_f

Math Gymnastics: What's it Good For?

Standard enthalpies of formation

Appendix L – page A29

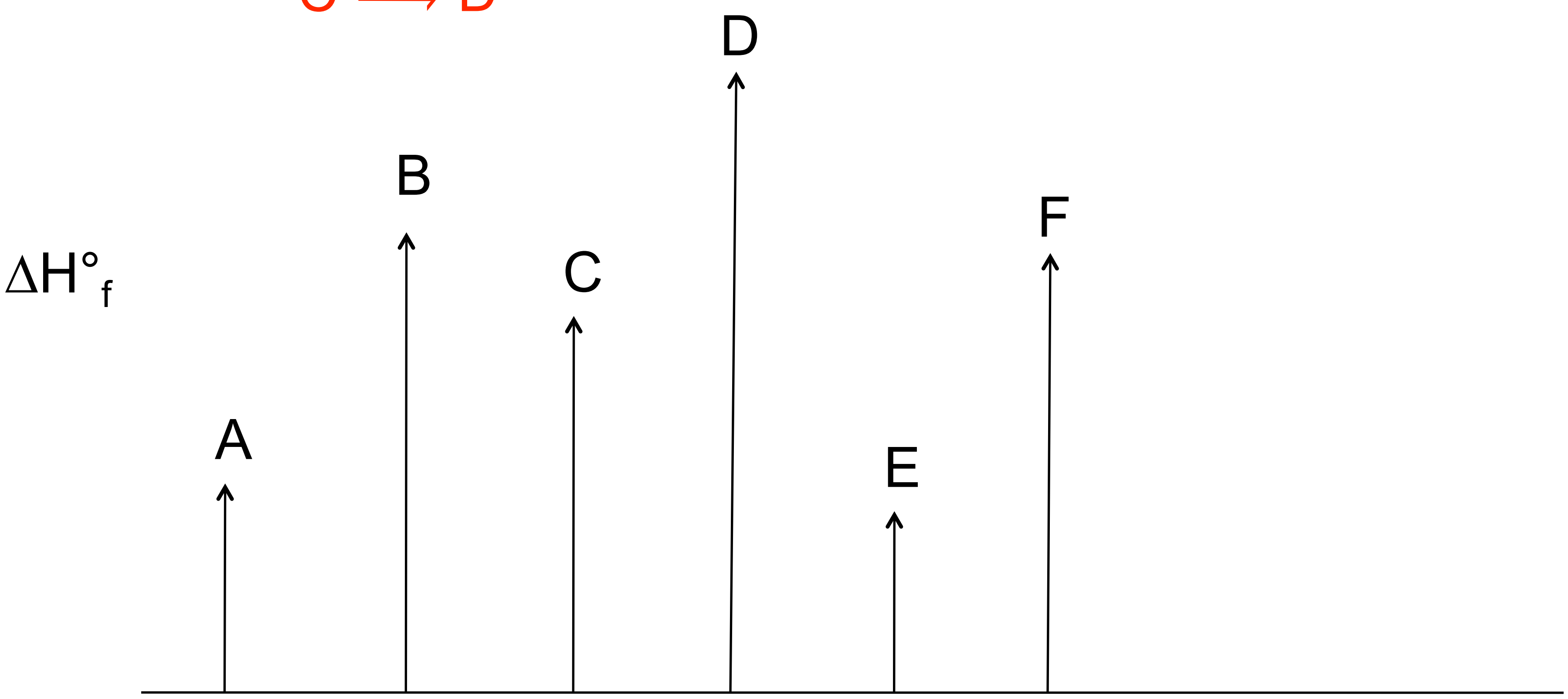


Math Gymnastics: What's it Good For?

Standard enthalpies of formation

Appendix L – page A29

$C \longrightarrow D$



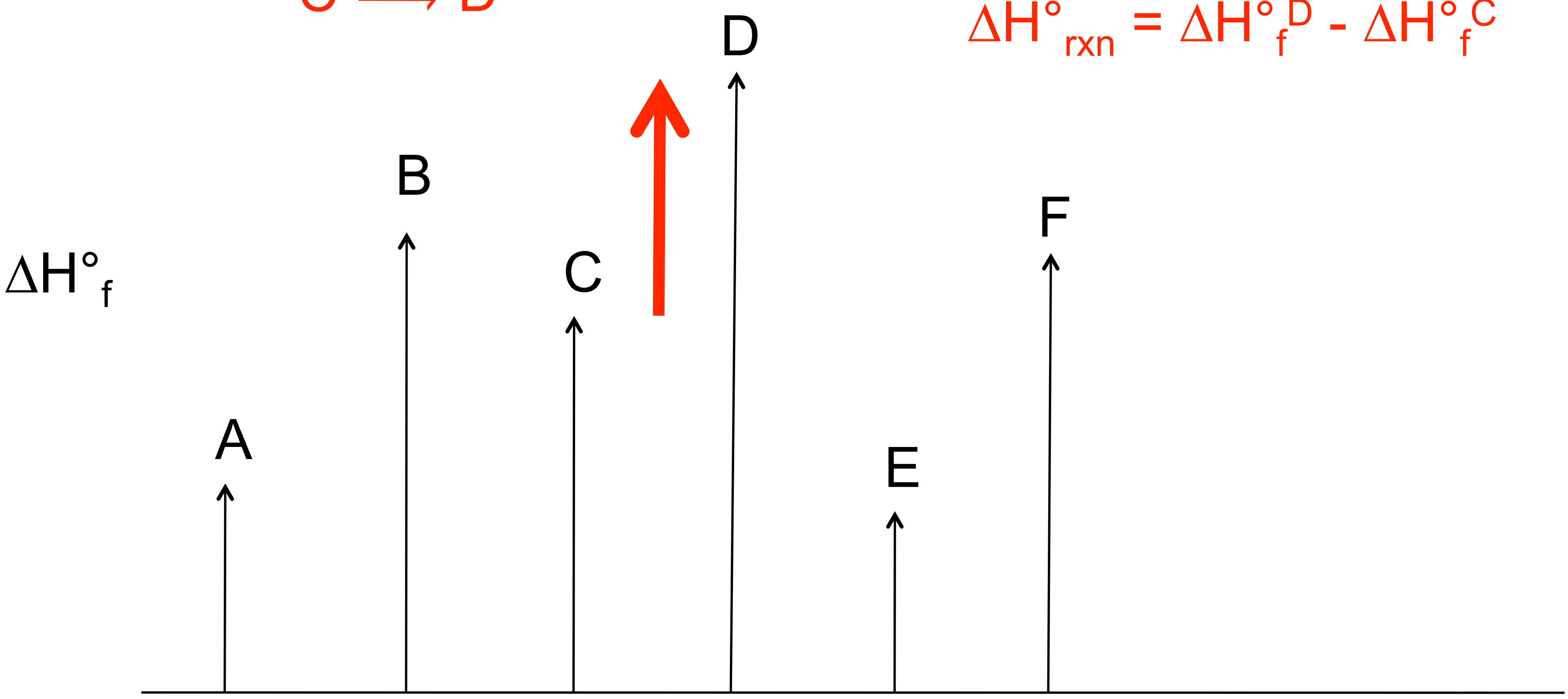
Math Gymnastics: What's it Good For?

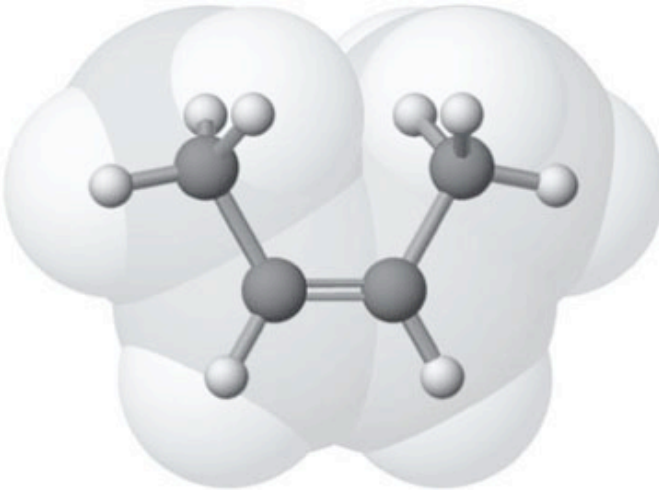
Standard enthalpies of formation

Appendix L – page A29

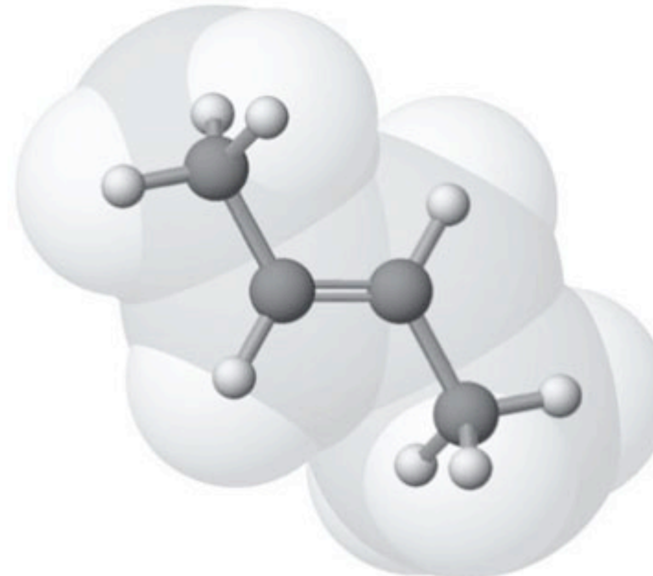
$C \longrightarrow D$

$\Delta H^\circ_{rxn} = \Delta H^\circ{}_f^{D} - \Delta H^\circ{}_f^{C}$

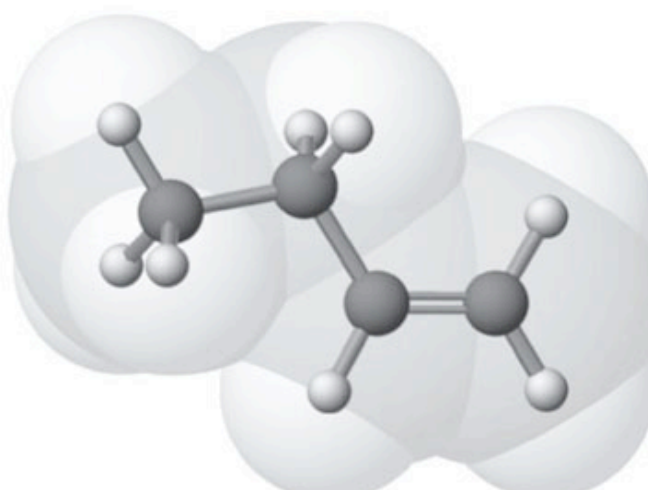




cis-2-butene



trans-2-butene



1-butene

Study Question #101, p. 252

TABLE 2 Energy Released by Combustion of Fossil Fuels

Substance	Energy Released (kJ/g)
Coal	29–37
Crude petroleum	43
Gasoline (refined petroleum)	47
Natural gas (methane)	50

Interchapter, Table 2, p. 257

TABLE 1 **Producing Electricity in the United States (2006)**

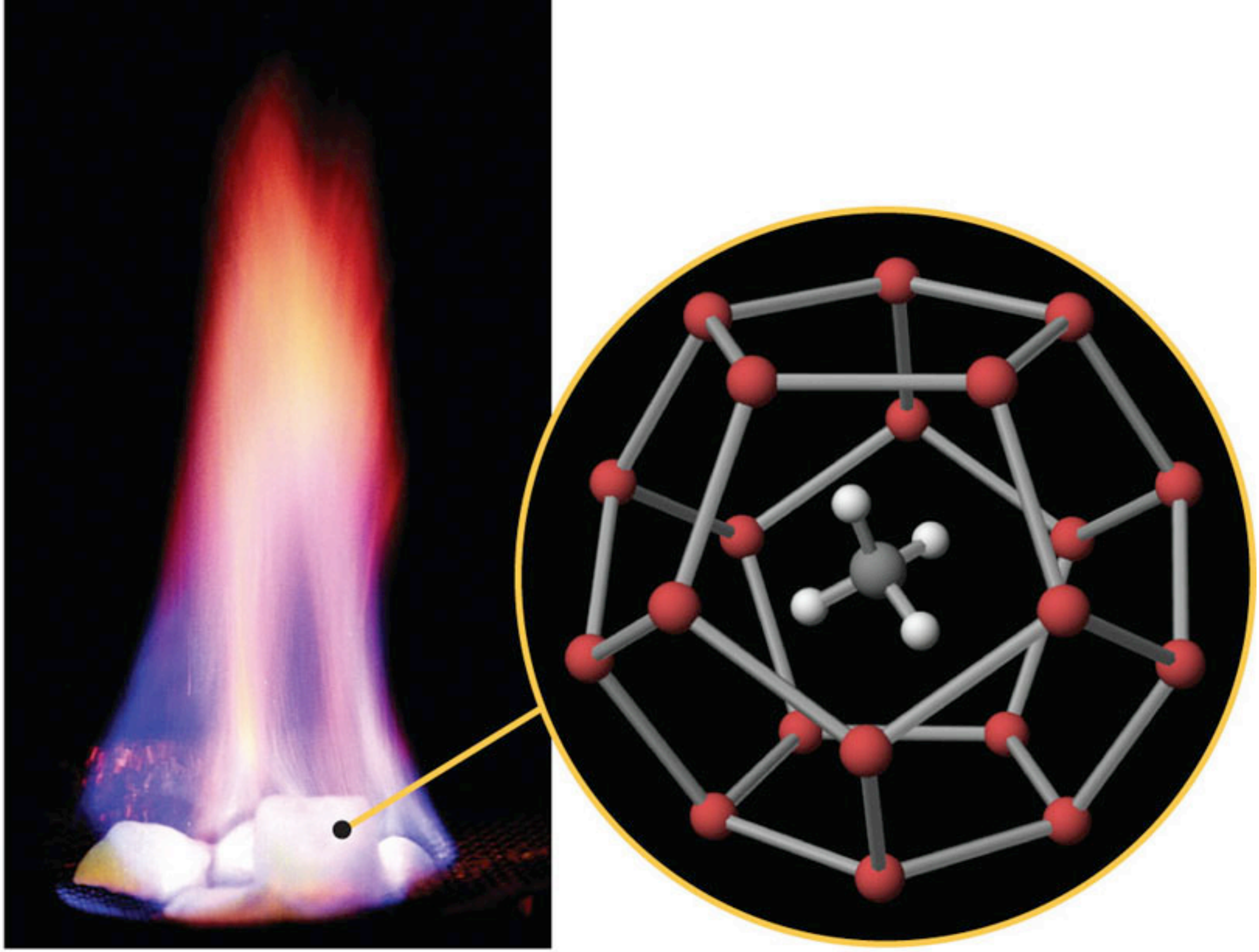
Coal	50%
Nuclear	19%
Natural gas	19%
Hydroelectric	7%
Petroleum	3%
Other renewables	2%

Interchapter, Table 1, p. 256

TABLE 3 Types of Coal

Type	Consistency	Sulfur Content	Heat Content (kJ/g)
Lignite	Very soft	Very low	28–30
Bituminous coal	Soft	High	29–37
Anthracite	Hard	Low	36–37

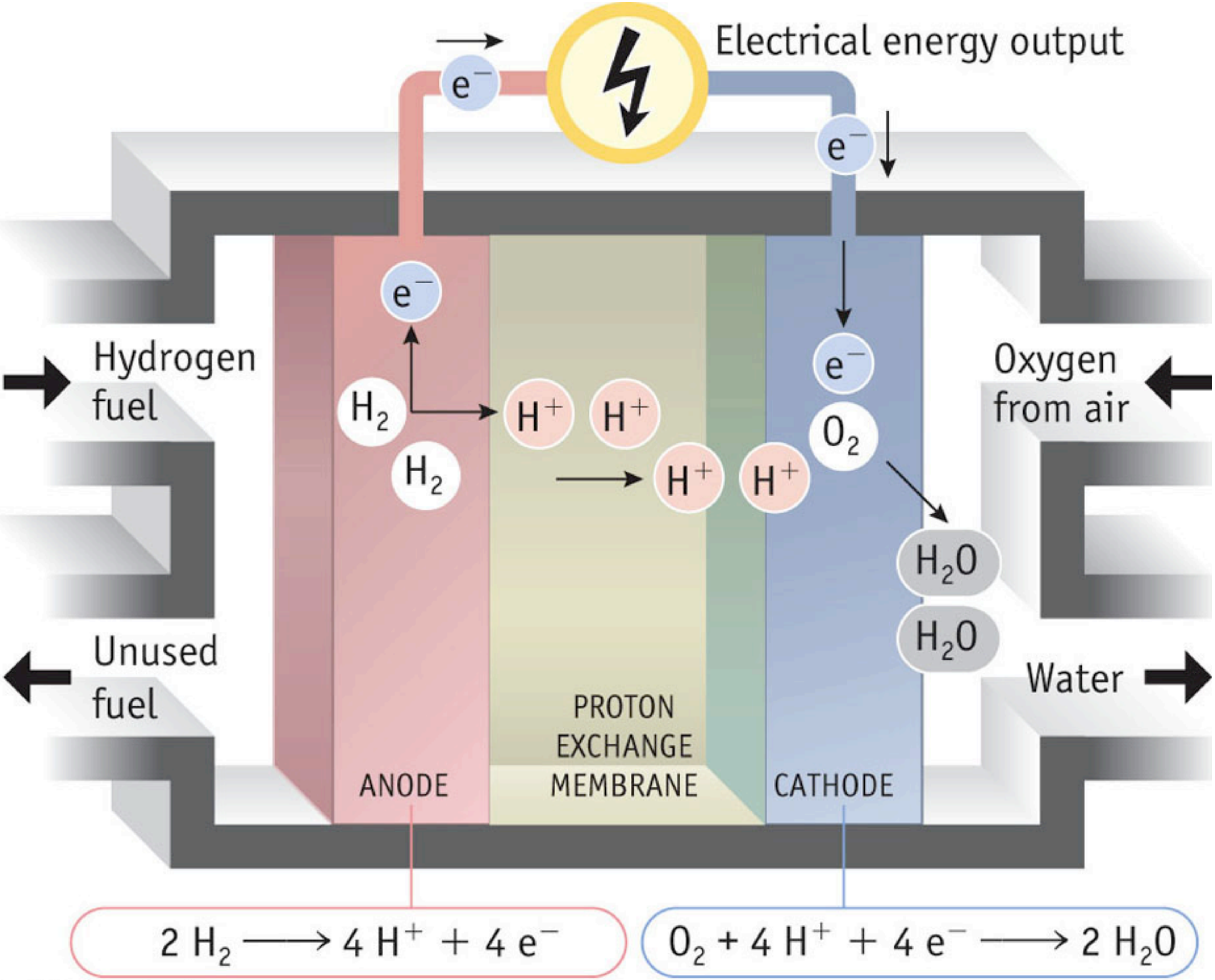
Interchapter, Table 3, p. 258



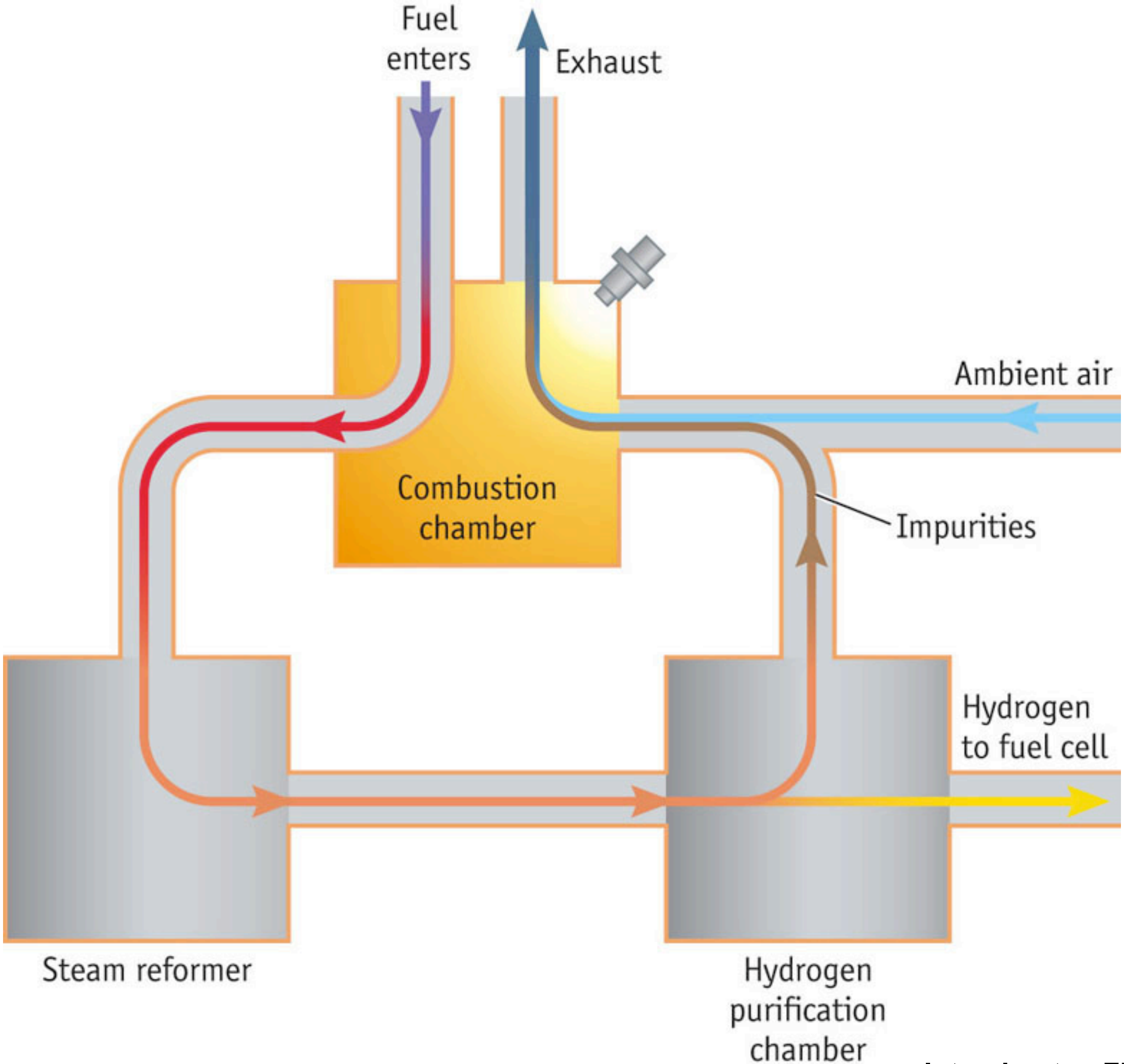
(a) Methane hydrate burns as methane gas escapes from the solid hydrate.

(b) Methane hydrate consists of a lattice of water molecules with methane molecules trapped in the cavity.

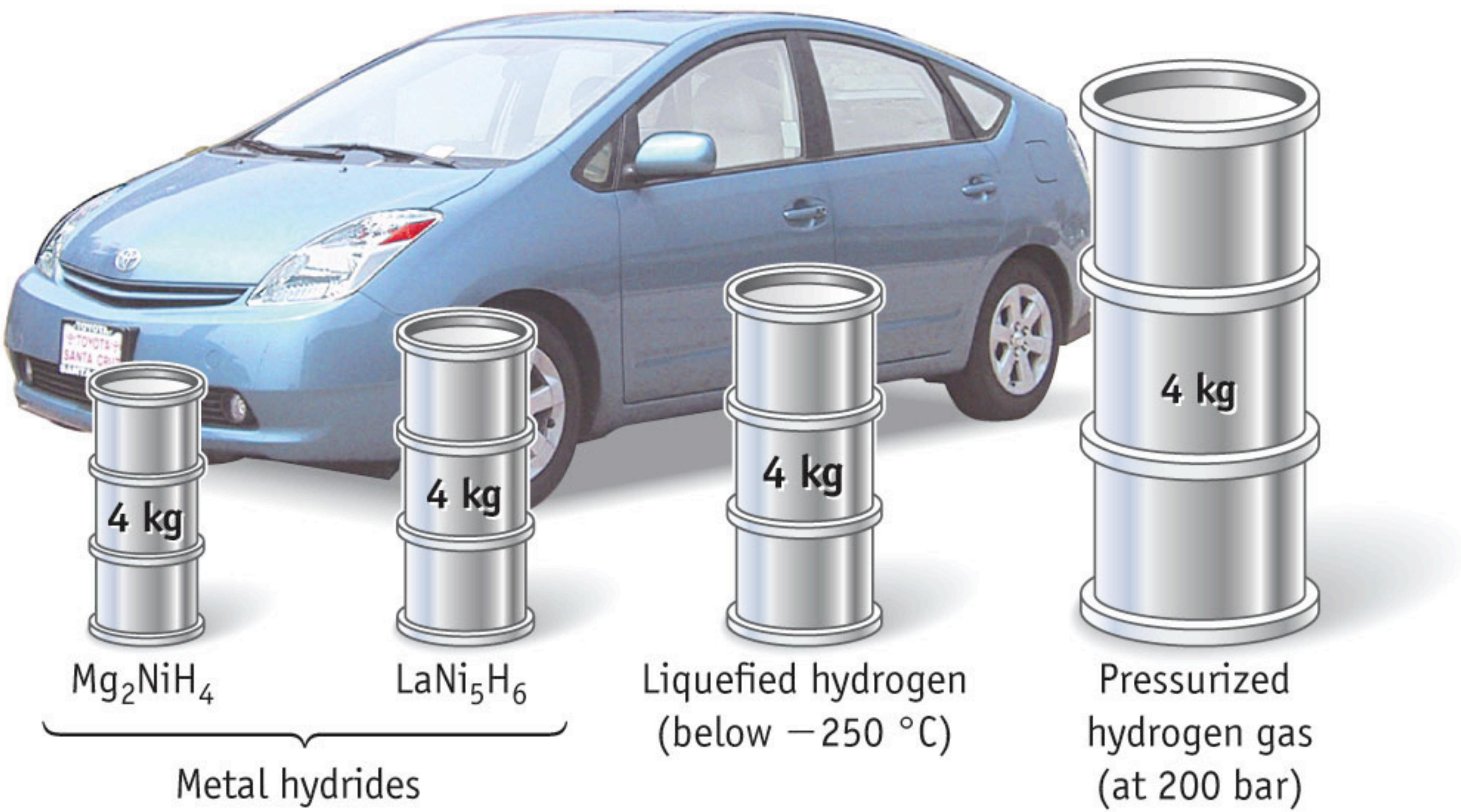
Interchapter, Fig. 5, p. 260



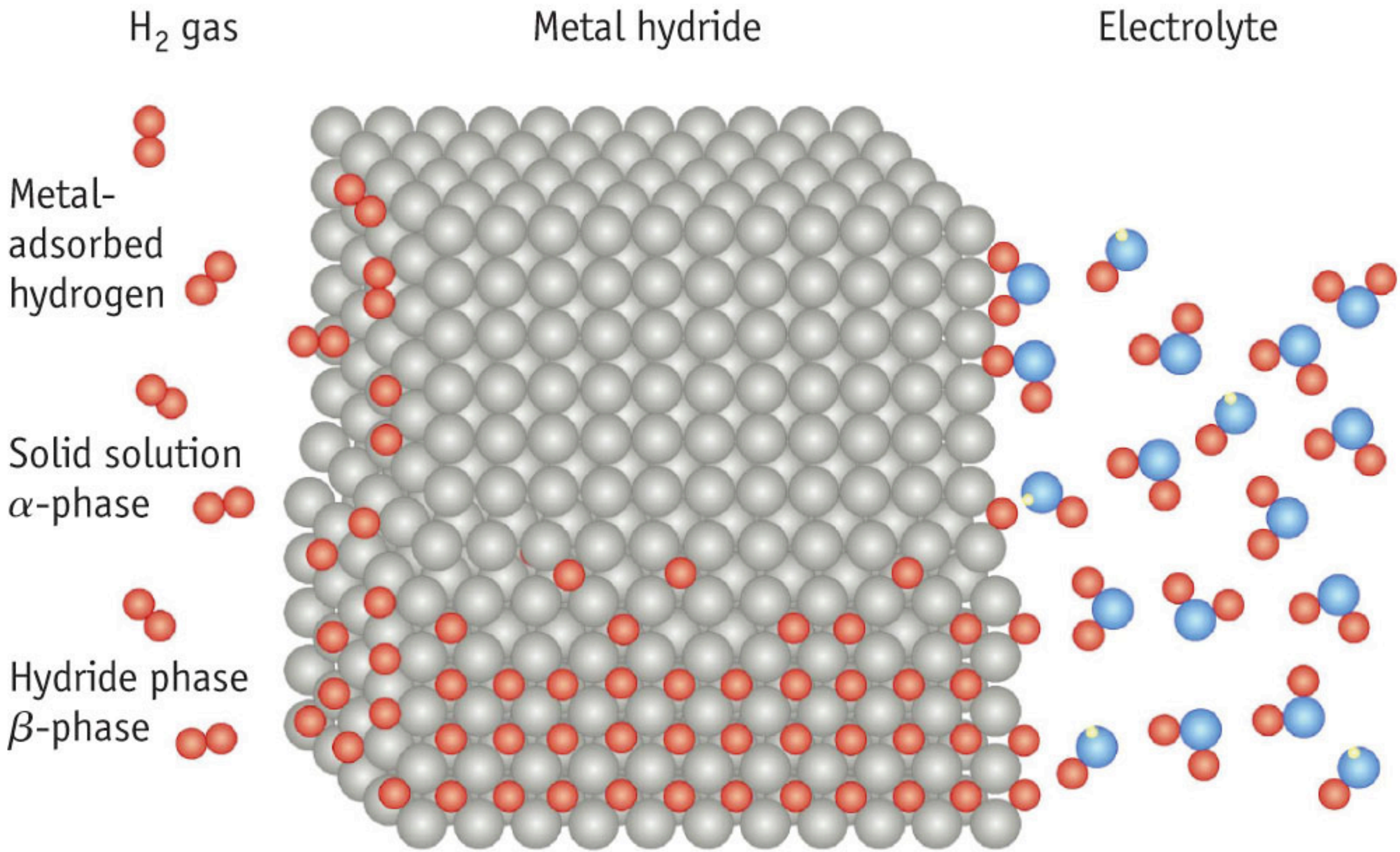
Interchapter, Fig. 9, p. 262



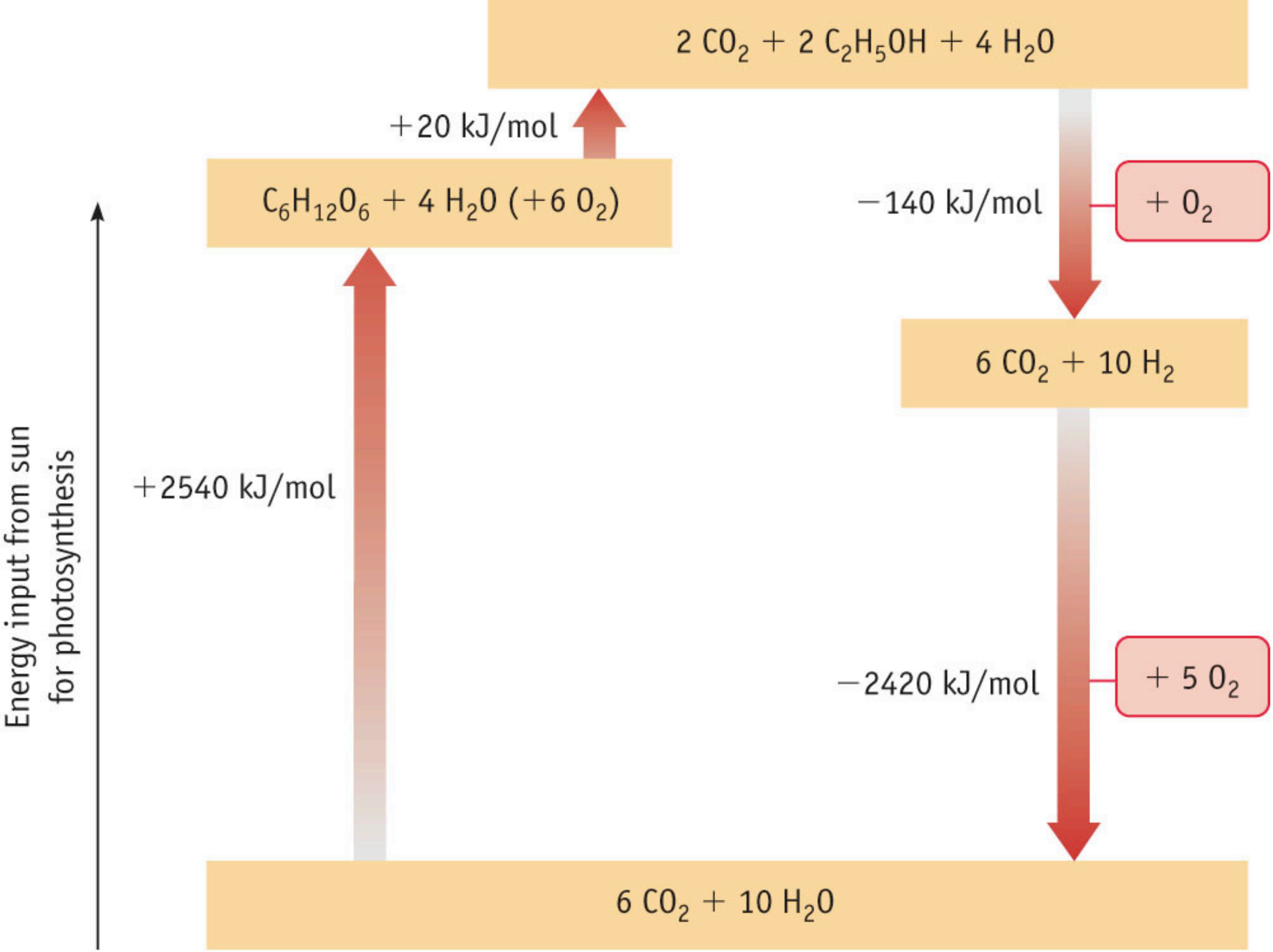
Interchapter, Fig. 11, p. 263



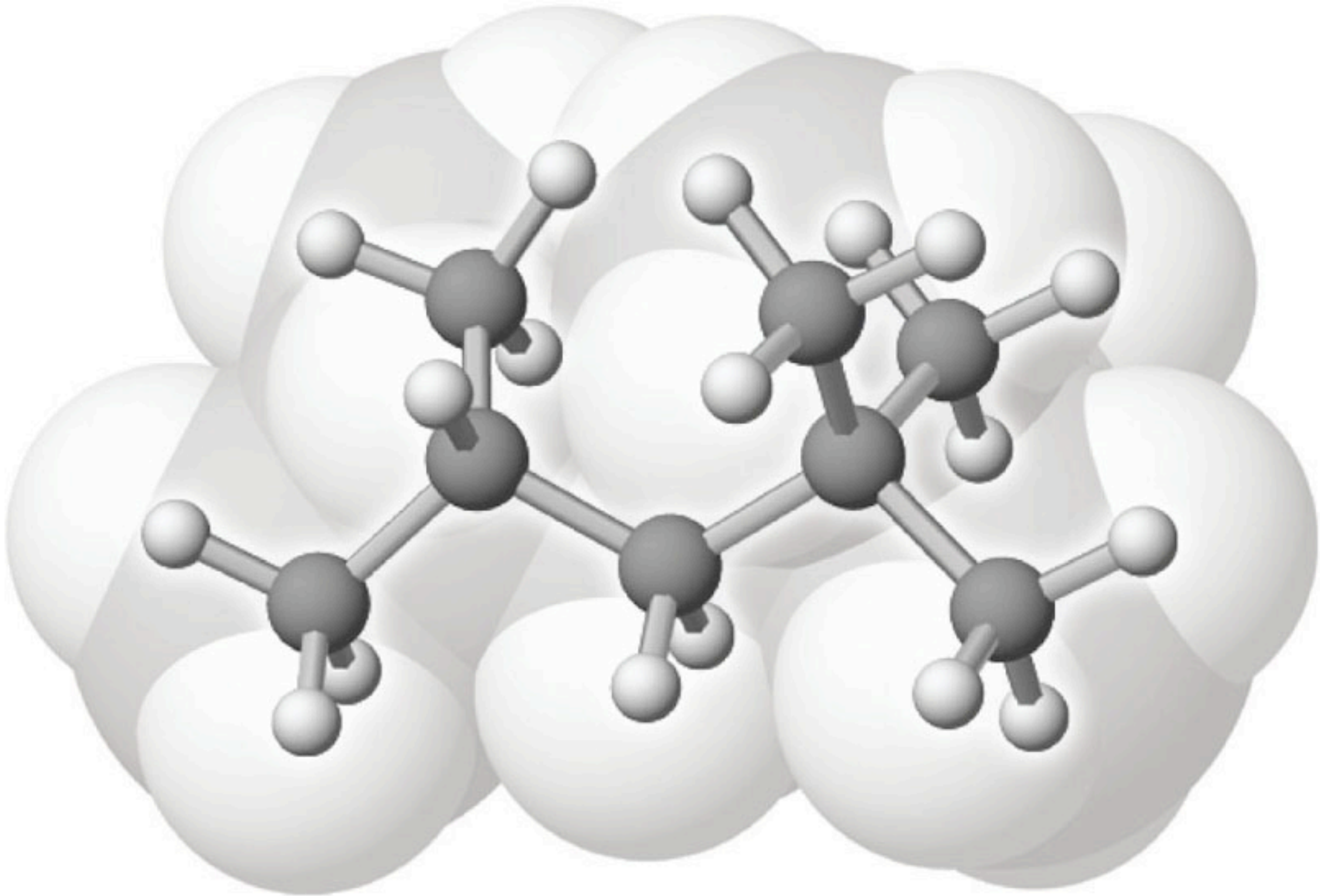
Interchapter, Fig. 12, p. 264



Interchapter, Fig. 13, p. 264



Interchapter, Fig. 16, p. 265



Isooctane
C_8H_{18}

Interchapter, p. 267