SOLUTIONS

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1) Consider the reaction shown below, in which $MgCl_2$ reacts with NaOH to produce $Mg(OH)_2$ and NaCl.

$$MgCl_2\ (aq) + 2\ NaOH\ (aq) \rightarrow Mg(OH)_2\ (s) + 2\ NaCl\ (aq)$$

A sample initially contains 0.02 mole of $MgCl_2$ and 0.03 mole of NaOH. The reaction then proceeds until one of the reactants is completely consumed.

Identify the limiting reagent and the amount of $Mg(OH)_2$ produced.

- ○ $MgCl_2$; 0.01 mole
- ● NaOH; 0.015 mole
- ○ $MgCl_2$; 0.02 mole
- ○ NaOH; 0.02 mole

2) The equation for the combustion of butane is shown below.

$$\underline{2}\ C_4H_{10}\ (g) + \underline{13}\ O_2\ (g) \rightarrow \underline{8}\ CO_2\ (g) + \underline{10}\ H_2O\ (l)$$

Balance the reaction by adding stoichiometric coefficients to the equation. Then calculate how many molecules of CO_2 will be formed from the combustion of 0.0829 g of butane, and select the correct answer below.

- ☒ 3.44×10^{21} CO_2 molecules
- ○ 8.59×10^{20} CO_2 molecules
- ○ 1.16×10^{25} CO_2 molecules
- ○ 2.15×10^{21} CO_2 molecules

3) An atom is excited from its ground state by absorbing a photon. It relaxes back to the ground state by emitting two photons, an orange photon at 600 nm and an infrared one at 1200 nm.
What is the wavelength of the absorbed photon?

- ○ 900 nm
- ○ 1800 nm
- ○ 1200 nm
- ☒ 400 nm
- ○ 600 nm

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4) A light beam with wavelength λ=700nm strikes a metal surface and causes emission of electrons.
If the same metal surface is struck by a light beam with wavelength λ=560nm, the kinetic energy of the electrons emitted by the surface will be

- [x] greater by a factor that depends on the metal's work function
- [ ] smaller by a factor that depends on the metal's work function
- [ ] the same
- [ ] smaller by a factor of 4/5
- [ ] greater by a factor of 5/4

5) Consider a single photon with wavelength λ, frequency ν and energy E.
What is the wavelength, frequency and energy of a beam of light containing 100 of these photons?

- [ ] 100 λ, 100 ν and 100 E
- [ ] 0.01 λ, 100 ν and 100 E
- [ ] 0.01 λ, ν and 100 E
- [x] λ, ν and 100 E
- [ ] 0.01 λ, 0.01 ν and 0.01 E
- [ ] 100 λ, 100 ν and E

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6) Ethylene, C_2H_4, is a small molecule that can link end-to-end with other ethylene molecules to form a chain. Structures are shown below for chains that result from linking n molecules of ethylene together.

$n = 1$ $n = 2$ large n

[The difference between single bonds (–) and double bonds (=) is not important here. Nor is the detailed connectivity between H and C atoms.]

i. Write a balanced reaction equation for this process.

$n\ C_2H_4 \longrightarrow C_{2n}H_{4n}$

ii. What is the mass of a chain with $n = 10$? Give your answer in units of g/mol.

$n = 10 \Rightarrow$ molecule is $C_{20}H_{40}$.

mass $= 20 \times 12 \frac{g}{mol} + 40 \times 1 \frac{g}{mol} = 280$ g/mol

Final Answer

280 g/mol

iii. Balance the following reaction equation for the bonding of ethylene molecules to form a chain with $n = 3$.

$\underline{3}\ C_2H_4 \rightarrow \underline{1}\ C_6H_{12}$

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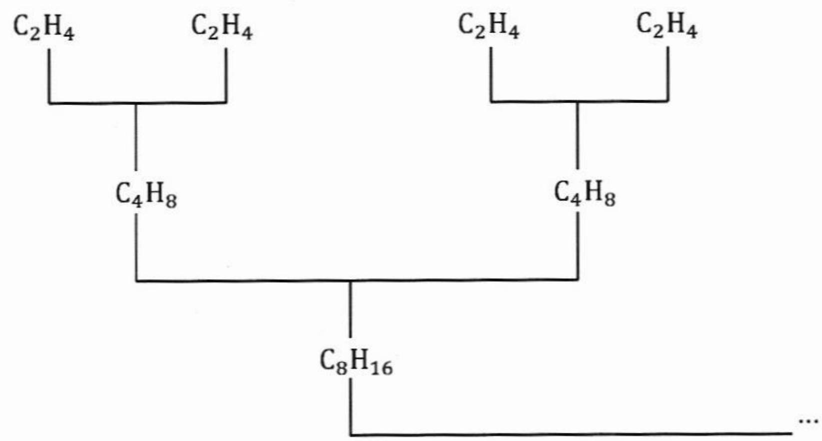
For the remaining parts of this question, consider a sample that initially contains 1 mole of C_2H_4 molecules. These molecules bond to one another in successive rounds, forming longer and longer chains at each stage, as depicted in the tree diagram below.



- In the first round, each C_2H_4 molecule bonds to another C_2H_4 molecule to form chains with $n = 2$.

$$C_2H_4 + C_2H_4 \rightarrow C_4H_8$$

This reaction goes to completion.

- In the second round, each $n = 2$ chain bonds to another $n = 2$ chain to form chains with $n = 4$.

$$C_4H_8 + C_4H_8 \rightarrow C_8H_{16}$$

This reaction goes to completion.

- Subsequent rounds similarly convert all chains of length n to chains of length $2n$.

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iv. How many rounds of binding are required to form chains with $n = 16$? How many moles of $n = 16$ chains are produced?

round 1 $n=1 \rightarrow 2$
round 2 $n=2 \rightarrow 4$
round 3 $n=4 \rightarrow 8$
⋮
round N $n=N \rightarrow 2N$

to produce a chain with $n=N$, 2^{x} rounds are needed ⇒ 4 rounds for $n=16$
(where $N=2^{x}$)

moles formed are then 2^{-x}

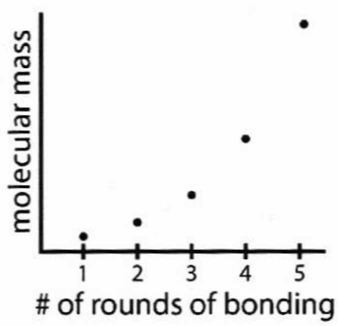
Final Answer

4 rounds

1/16 moles

v. Which of the plots below correctly shows the mass of a chain molecule that is present after each round of bonding? Mark the appropriate circle.

☒ exponential growth!



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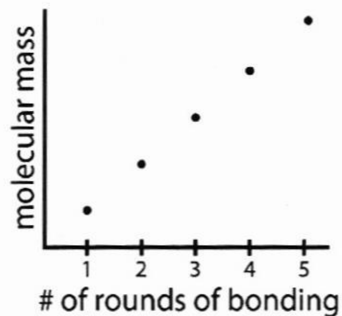

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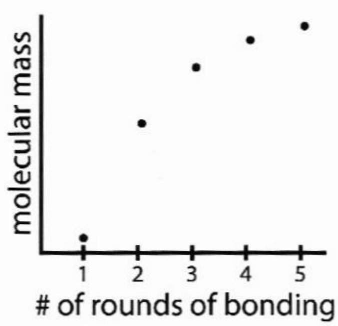

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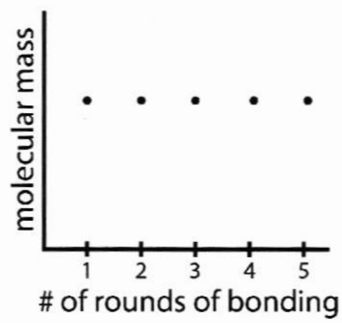

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vi. After many rounds of bonding, only a single molecule remains. What is the mass of this one remaining molecule?

We started with 1 mol of ethylene which weighs 28 g. Mass is conserved so this is the final weight as well.

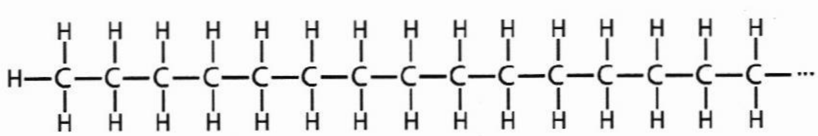
28 g Final Answer

vii. When only a single molecule remains, how many carbon nuclei does it contain?

We started with 2 mol 'C' nuclei in ethylene & this conserved. Thus, we will have $2 N_A$ 'C' nuclei.

1.2×10^{24} Final Answer

viii. If this last remaining molecule were pulled completely straight, as in the picture below, how long would it be? For reference, the length of C–H and C–C bonds is about 1Å.



The distance from the first carbon nucleus to the last is about:

- ○ 10 Å
- ○ 100 nm
- ○ 1μm
- ○ 1 m
- ○ 1 km
- ☒ 10^{11} km

length ≈ 10^{-10} m × 6.02×10^{23} Å ~ 10^{14} m ~ 10^{11} km

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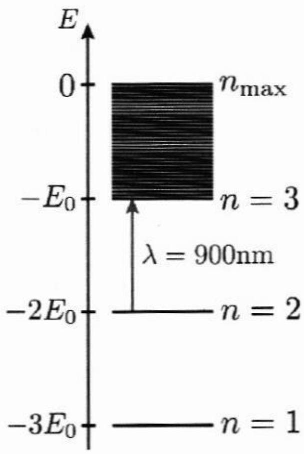
7) The diagram below shows the allowed energy levels of a certain molecule, which include a large number of states with energy between $E = -E_0$ and $E = 0$. The state with highest energy is labeled n_{max}.



i. A transition from $n = 2$ to $n = 1$ is accompanied by emission of a photon with wavelength $\lambda = 900$ nm, as shown in the energy level diagram. Using this information, calculate the value of E_0 in units of kJ/mol.

$\Delta E = -2E_0 - (-3E_0) = E_0 = \frac{hc}{900\text{nm}} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}\times3\times10^{8}\ \text{m/s}}{900\times10^{-9}\ \text{m}}$

$\Delta E = 2.21\times10^{-19}\ \text{J}\times6\times10^{20}\ \frac{\text{kJ}}{\text{mol}}$

130 kJ/mol Final Answer

ii. What wavelength of light would be absorbed in a transition from $n = 2$ to n_{max}?

- ○ 300 nm
- ☒ 450 nm
- ○ 750 nm
- ○ 900 nm
- ○ 1800 nm

$\Delta E_{2\to max} = 2E_0$

$\Rightarrow \lambda_{2\to max} = \frac{900\ \text{nm}}{2}$

(inversely proportional to energy)

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iii. For the states shown above, what transition (or transitions) involves the largest change in this molecule's energy, and by how much does its energy change? (Give answer in units of E_0).

$n = 1$ to n_{max} has highest energy change

$\Delta E = 3E_0$

iv. What is the shortest wavelength of light that can be absorbed by this molecule? All of the energy levels shown should be considered as possible initial states.

shortest λ corresponds to largest ΔE.

$\Delta E_{max} = 3E_0 \Rightarrow \lambda_{min} = \frac{900 \text{ nm}}{3}$

300 nm ________ Final Answer

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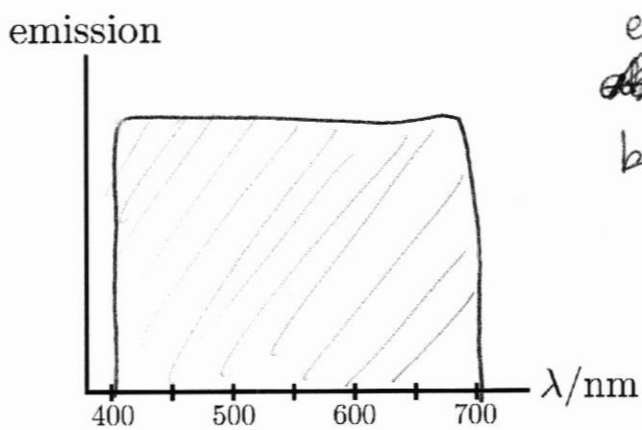
v. On the graph below, sketch the complete emission spectrum for this molecule over the range of wavelengths shown. (Transitions that emit light outside this range do not need to be considered.) Recall that the complete emission spectrum includes transitions from all possible excited states.

You may assume that excited states between $n = 3$ and n_{max} are so numerous that the spectrum is very smooth.



emits ~~absorbs~~ everything between 400 nm & 700 nm

vi. Based on the spectrum you drew in part (v), describe the appearance of light **emitted** (not reflected) by this substance as it undergoes all of its possible transitions.

It appears white as emitted light covers all of the visible spectrum.

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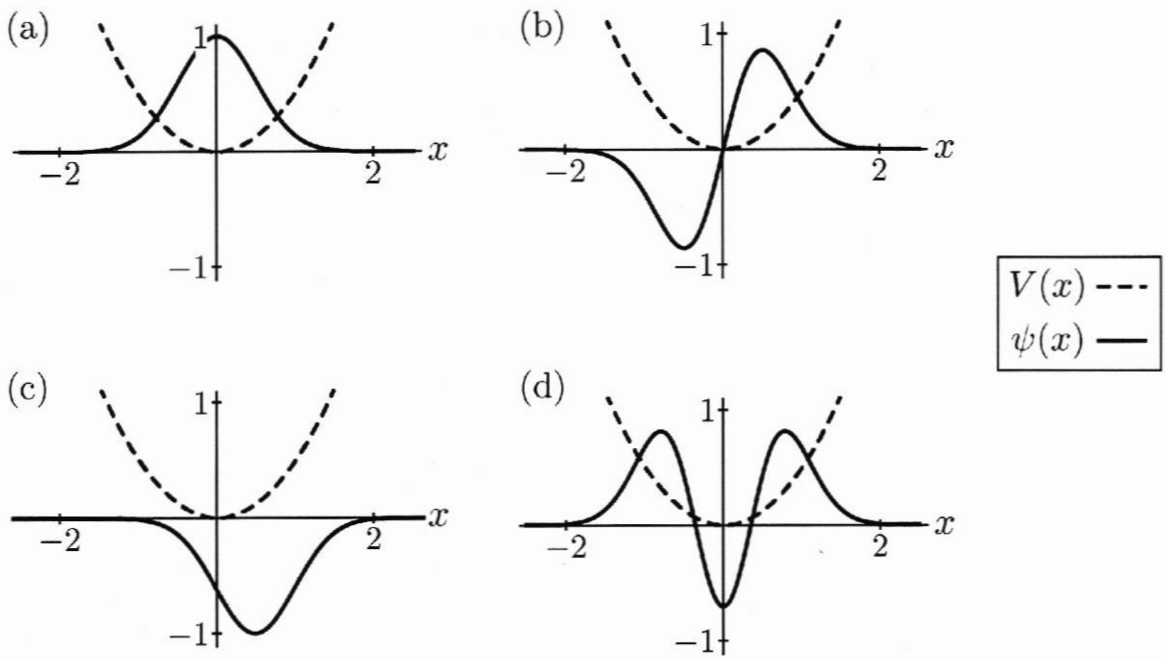
8) Consider an electron with position x, in a 1-dimensional potential $V(x)$. Panels (a), (b), (c) and (d) of the figure below show 4 different wavefunctions $\psi(x)$ for this electron (solid lines), alongside the potential $V(x)$ (dashed lines).



i. True or false: The kinetic energy of an electron described by the wavefunctions in panels (a) and (c) is equal. Explain your answer in 1-2 sentences.

True, because they have the same curvature.

ii. True or false: The potential energy of an electron described by the wavefunctions in panels (a) and (b) is equal. Explain your answer in 1-2 sentences.

False, (a) is lower than (b) as the electron probability in (a) is maximum where V(x) is minimized.

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iii. Which wavefunction(s) has the highest probability of finding the electron at $x \geq 0$?

(c) has the highest probability because the wavefunction is centered about a value > 0.

iv. Which wavefunction(s) has the lowest ***total*** energy?

(a) → lowest Kinetic + potential

v. Which wavefunction(s) has the lowest kinetic energy?

(a), (c) → lowest curvature, no nodes and their width is the same

vi. If the potential is removed (setting $V(x) = 0$ at all x), which wavefunction(s) has the highest kinetic energy?

(d) → maximum # of nodes