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Topic 5.1: Reaction Rates

Revision Notes · AP Chemistry

UNIT 5 · KINETICS

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What the Rate Measures

A reaction rate measures how fast a concentration changes. It is the change in concentration of a reactant or product divided by the time the change takes.

Concentration is measured in mol/L, written M, so a rate carries units of mol L^{-1} s^{-1}, usually shortened to M/s. Rates in M/min appear when a reaction is slow.

A rate is always reported as a positive number, even though reactant concentrations fall.

Rate is not an amount. A change of 0.10 mol/s is not a rate: spread through a larger volume, the same molar change produces a smaller concentration change.

Average Rate Over an Interval

The average rate of disappearance of a reactant A across an interval is $-\Delta[A]/\Delta t$: the fall in [A] divided by the elapsed time.

The negative sign has one job. Because [A] falls, $\Delta[A]$ is negative, and the sign in front turns the result positive, matching the rule that rates are positive.

For a product the same idea needs no sign fix: the average rate of appearance is $+\Delta[C]/\Delta t$, and $\Delta[C]$ is already positive.

One interval gives one number, and that number averages everything inside the interval; it says nothing about how the rate varied moment by moment within it.

Measured interval by interval, the average rate shrinks as the reaction proceeds, because the reaction slows as reactants are used up. The first interval is almost always the fastest.

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Instantaneous Rate: The Slope at One Moment

The instantaneous rate is the rate at a single instant. On a graph of concentration against time it is the slope of the tangent to the curve at that time.

To measure it, draw the line that just touches the curve at the chosen time, extend it well beyond the point, and read two widely separated points on the line itself: the slope is their concentration difference divided by their time difference. The points come from the line, not from the curve.

For a reactant the tangent slopes downward and the slope is negative; the rate of disappearance is its size, reported positive. For a product the slope is already positive and gives the rate of appearance directly.

The tangent at time zero gives the initial rate: the fastest rate of the run, measured while concentrations are still the starting ones.

The two kinds of rate join up at small intervals: shrink the interval around a moment and the average rate over it closes in on the tangent slope there.

One Reaction, One Rate: Dividing by the Coefficient

The species in one reaction do not change at the same speed. In $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$, NO disappears twice as fast as O_2, because the equation consumes them in a 2 to 1 ratio.

Dividing each rate of change by its own coefficient collapses them all into a single number, the reaction rate: rate $= -(1/2)(\Delta[NO]/\Delta t) = -(\Delta[O_2]/\Delta t) = (1/2)(\Delta[NO_2]/\Delta t)$.

For a general equation $aA + bB \rightarrow cC + dD$ the pattern is rate $= -(1/a)(\Delta[A]/\Delta t) = -(1/b)(\Delta[B]/\Delta t) = (1/c)(\Delta[C]/\Delta t) = (1/d)(\Delta[D]/\Delta t)$. Reactants take the negative sign, products do not, and every coefficient inverts: a coefficient of 2 becomes a factor of one half.

Running the rule backwards converts the reaction rate into any species' rate of change: multiply by the species' coefficient, with a negative sign for a reactant and a positive sign for a product.

Keep the two quantities distinct: the rate of disappearance of NO above is a real, measurable number, but it is twice the reaction rate. A question asking for the reaction rate wants the divided value.

Why the Rate Falls as a Reaction Runs

At the start, reactant concentrations are highest and the changes are steepest. The reactant curve falls sharply; the product curve climbs sharply.

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As reactants are consumed, each litre holds fewer reactant particles, encounters between them happen less often, and the change per second shrinks. The curves flatten: the reactant curve levels off as the reactant runs out, the product curve at its final concentration.

A flat product curve is itself a reading: the reaction has effectively stopped because a reactant is exhausted.

Worked Examples

Example 1: Average rates from a data table. The concentration of a reactant X is 0.500 M at 0 s, 0.420 M at 20 s, 0.352 M at 40 s and 0.296 M at 60 s. From 0 to 20 s the fall is 0.080 M, so the average rate of disappearance is 0.080 ÷ 20 = 0.00400 M/s. From 20 to 40 s it is (0.420 − 0.352) ÷ 20 = 0.00340 M/s, and from 40 to 60 s, (0.352 − 0.296) ÷ 20 = 0.00280 M/s. Same interval length, smaller rate each time: the reaction slows as X is consumed.

Example 2: An instantaneous rate from a tangent. On a graph of [A] against time, the tangent at t = 20 s passes through (0 s, 0.80 M) and (50 s, 0.30 M). The slope is (0.30 − 0.80) ÷ 50 = −0.010 M/s. The instantaneous rate of disappearance of A at 20 s is therefore 0.010 M/s. Both readings lie on the tangent line; neither has to lie on the curve.

Example 3: Converting between species. For $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$, suppose $[NH_3]$ is changing at −0.12 M/s at one instant. The reaction rate is 0.12 ÷ 4 = 0.030 M/s. Oxygen changes at $-5 \times 0.030 = -0.15$ M/s, so it disappears at 0.15 M/s. NO appears at $4 \times 0.030 = 0.12$ M/s, and H_2O appears at $6 \times 0.030 = 0.18$ M/s. One reaction rate, four different species rates, all fixed by the coefficients.

Example 4: Starting from a product. For $2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$, O_2 appears at 0.0080 M/s at one instant. Each O_2 formed costs two N_2O_5, so N_2O_5 disappears at $2 \times 0.0080 = 0.016$ M/s, NO_2 appears at $4 \times 0.0080 = 0.032$ M/s, and the reaction rate is the O_2 figure itself, 0.0080 M/s, because O_2 has coefficient 1.

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Traps That Cost Marks in Topic 5.1

Reporting a species rate as the reaction rate. The rate of disappearance of a reactant with coefficient 2 is twice the reaction rate. Divide by the coefficient before calling a number the reaction rate.

Multiplying by the coefficient instead of inverting it. Writing $-2(\Delta[NO]/\Delta t)$ for the NO reaction overstates the rate fourfold: the correct factor is one half, not two.

Losing the sign. $\Delta[A]$ for a reactant is negative. Leave out the compensating negative sign and the rate comes out negative, which no reaction rate can be. Keep the quantities separate: a rate of change may be negative; a rate may not.

Reading the curve instead of the tangent. An instantaneous rate comes from two points on the extended tangent line. Taking two points on the curve either side of the moment gives an average rate across that span, not the instantaneous rate.

Quoting mol/s as a rate. Rate is concentration per unit time, mol L^{-1} s^{-1}. The litre matters: the same molar change spread through twice the volume is half the rate.

Assuming the rate stays constant. The average rate from the first interval cannot be carried forward to predict later concentrations: the reaction slows as reactants deplete, so each later interval changes less.

Adding a negative sign to a product slope. A product curve rises and its slope is positive; that slope is the rate of appearance with no adjustment. The negative sign belongs to reactants only.

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Key Relationships to Remember

- Reaction rate = change in concentration ÷ time taken; units mol L^{-1} s^{-1} (M/s) or M/min; always a positive number
- Average rate of disappearance of A over an interval: $-\Delta[A]/\Delta t$; average rate of appearance of a product: $+\Delta[\text{product}]/\Delta t$
- Instantaneous rate = the size of the tangent slope on a concentration against time graph at that moment; the initial rate is the tangent slope at t = 0
- As the interval shrinks around a moment, the average rate over it approaches the instantaneous rate at that moment
- For $aA + bB \rightarrow cC + dD$: rate = $-(1/a)(\Delta[A]/\Delta t) = -(1/b)(\Delta[B]/\Delta t) = (1/c)(\Delta[C]/\Delta t) = (1/d)(\Delta[D]/\Delta t)$
- Rate of change of any species = its coefficient × the reaction rate, negative for a reactant and positive for a product
- Rates fall as reactants are consumed: the reactant curve falls and flattens, the product curve rises and flattens, both steepest at the start

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