**Iron (III) Oxide**

Fe2O3 → 2Fe3+ + 3O2+

2Fe3+ + H2O2→ 2Fe2+ + O2 + 2H+

2Fe2+ + H2O2 + 2H+ → 2Fe3+ + 2H2O

2H2O2 → 2H2O + O2

**Copper (II) Oxide**

CuO→ Cu2+ + O2-

Cu2+ + ½H2O2 + H+ → Cu3+ + H2O

Cu3+ + ½H2O2→ Cu2+ + ½O2 + H+

H2O2 → H2O + ½O2

**Manganese (IV) Oxide**

MnO2 → Mn4+ + 2O2-

Mn4+ + H2O2→ Mn2+ + O2 + 2H+

Mn2+ + H2O2 + 2H+ → Mn4+ + 2H2O

2H2O2 → 2H2O + O2

**Lead (II, IV) Oxide**

Pb3O4 → 2Pb2+ + Pb4+ + 4O2-

Pb4+ + H2O2 → Pb2+ + O2 + 2H+

Pb2+ + H2O2 + 2H+ → Pb4+ + 2H2O

2Pb2+ + Pb4+ + 3H2O2 + 2H+ → 2Pb4+ + Pb2+ + 4H2O + O2

2Pb4+ + Pb2+ + 3H2O2 → Pb4+ + 2Pb2+ + 2H2O + 2O2 + 2H+

6H2O2 → 6H2O + 3O2

**Potassium Iodide**

KI → K+ + I-

I- + H2O2 → H2O + OI-

OI- + H2O2 → H2O + O2 + I-

2H2O2 → 2H2O + O2

**Experiment Results**

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| ***Table-1***: Data and observations for **Manganese (IV) Oxide** | | | | | | | | | | | | | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Raw data | | | | | |  | Processed data – rate of reaction | | | | | |
| Volume of gas *V*  (cm3)  ± 2.5 cm3 instrument error | Time *t* (Seconds) | | | | | Average time *tµ* (Seconds)  with aggregate error | | | Rate *r* (cm3 s-1)  with aggregate error | | |
| Trial 1 | Trial 2 | Trial average  with aggregate error | | |
| Average initial temperature across trials (°C) | 21.1  ±0.2 | ± 0.01 seconds instrument error | |
| Average mass of catalyst across trials (grams) | 1.019  ±0.003 | 10.0 | 34.11 | 30.62 | 32 | ± | 2 |
| 20.0 | 60.72 | 61.45 | 61.1 | ± | 0.4 | 47 | ± | 3 | 0.3 | ± | 0.2 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 | 30.0 | 96.78 | 93.29 | 95 | ± | 2 | 78 | ± | 2 | 0.29 | ± | 0.07 |
| 40.0 | 133.92 | 140.63 | 137 | ± | 3 | 116 | ± | 5 | 0.24 | ± | 0.04 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 | 50.0 | 193.05 | 188.23 | 191 | ± | 2 | 164 | ± | 6 | 0.19 | ± | 0.03 |
| 60.0 | 260.47 | 256.87 | 259 | ± | 2 | 225 | ± | 4 | 0.15 | ± | 0.02 |
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| Qualitative Observations | | | | | | | | | | | | | | | |
| * Catalyst is a finely powdered black solid. * Instant rapid bubbling when the catalyst is released into the prepared H2O2 solution. * Catalyst has poor solubility, mostly remaining solid in the solution as black suspensions. | | | | | | | | | | | | | | | |

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| ***Table-2***: Data and observations for **Lead (II, IV) Oxide** | | | | | | | | | | | | | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Raw data | | | | | |  | Processed data – rate of reaction | | | | | |
| Volume of gas *V*  (cm3)  ± 2.5 cm3 instrument error | Time *t* (Seconds) | | | | | Average time *tµ* (Seconds)  with aggregate error | | | Rate *r* (cm3 s-1)  with aggregate error | | |
| Trial 1 | Trial 2 | Trial average  with aggregate error | | |
| Average initial temperature across trials (°C) | 21.2  ±0.1 | ± 0.01 seconds instrument error | |
| Average mass of catalyst across trials (grams) | 1.016  ±0.002 | 10.0 | 5.82 | 6.25 | 6.0 | ± | 0.2 |
| 20.0 | 10.27 | 9.78 | 10.0 | ± | 0.3 | 8.0 | ± | 0.5 | 3 | ± | 1 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 | 30.0 | 15.61 | 13.42 | 15 | ± | 1 | 12 | ± | 1 | 1.9 | ± | 0.6 |
| 40.0 | 21.52 | 22.63 | 22.1 | ± | 0.6 | 18 | ± | 2 | 1.7 | ± | 0.4 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 | 50.0 | 28.13 | 30.22 | 29 | ± | 1 | 26 | ± | 2 | 1.5 | ± | 0.3 |
| 60.0 | 35.09 | 37.56 | 36 | ± | 1 | 33 | ± | 2 | 1.4 | ± | 0.2 |
|  | | | | | | | | | | | | | | | |
| Qualitative Observations | | | | | | | | | | | | | | | |
| * Catalyst is a finely powdered, bright orange solid. * Instant bubbling when the catalyst is released into the prepared H2O2 solution. * Catalyst has poor solubility, mostly remaining solid in the solution as orange suspensions. | | | | | | | | | | | | | | | |

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| ***Table-3***: Data and observations for **Potassium Iodide**, where the system is left **undisturbed** | | | | | | | | | | | | | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Raw data | | | | | |  | Processed data – rate of reaction | | | | | |
| Volume of gas *V*  (cm3)  ± 2.5 cm3 instrument error | Time *t* (Seconds) | | | | | Average time *tµ* (Seconds)  with aggregate error | | | Rate *r* (cm3 s-1)  with aggregate error | | |
| Trial 1 | Trial 2 | Trial average  with aggregate error | | |
| Average initial temperature across trials (°C) | 20.9  ±0.2 | ± 0.01 seconds instrument error | |
| Average mass of catalyst across trials (grams) | 1.043  ±0.003 | 10.0 | 30.63 | 32.67 | 32 | ± | 1 |
| 20.0 | 65.85 | 70.51 | 68 | ± | 2 | 48 | ± | 3 | 0.3 | ± | 0.1 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 | 30.0 | 103.59 | 108.92 | 106 | ± | 3 | 85 | ± | 5 | 0.26 | ± | 0.07 |
| 40.0 | 143.13 | 152.28 | 148 | ± | 5 | 123 | ± | 7 | 0.25 | ± | 0.05 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 | 50.0 | 185.73 | 191.56 | 189 | ± | 3 | 164 | ± | 8 | 0.23 | ± | 0.04 |
| 60.0 | 230.77 | 262.81 | 250 | ± | 20 | 210 | ± | 20 | 0.22 | ± | 0.04 |
|  | | | | | | | | | | | | | | | |
| Qualitative Observations | | | | | | | | | | | | | | | |
| * Catalyst is a powdered crystalline white solid. * The catalyst is highly soluble, the solid catalyst dissolves instantly when released into the prepared H2O2 solution, followed by bubbling. * The originally clear and colourless H2O2 solution turns into a clear brown colour after the catalyst is dissolved in it. * The reactive system is sensitive to motion, where disturbing the system leads to observably more rapid bubbling. | | | | | | | | | | | | | | | |

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| ***Table-4***: Data and Observations for **Copper (II) Oxide** | | | | | | | | | | | | | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Raw data | | | | | |  | Processed data – rate of reaction | | | | | |
| Volume of gas *V*  (cm3)  ± 2.5 cm3 instrument error | Time *t* (Seconds) | | | | | Average time *tµ* (Seconds)  with aggregate error | | | Rate *r* (cm3 s-1)  with aggregate error | | |
| Trial 1 | Trial 2 | Trial average  with aggregate error | | |
| Average initial temperature across trials (°C) | 20.0 ±0.1 | ± 0.01 seconds instrument error | |
| Average mass of catalyst across trials (grams) | 0.968 ±0.004 | 10.0 | 179.93 | 217.67 | 200 | ± | 20 |
| 20.0 | 444.61 | 482.19 | 460 | ± | 20 | 330 | ± | 40 | 0.04 | ± | 0.02 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 | 30.0 | 836.17 | 1004.02 | 920 | ± | 80 | 690 | ± | 90 | 0.022 | ± | 0.007 |
| 40.0 | 1351.71 | 1572.23 | 1500 | ± | 100 | 1200 | ± | 200 | 0.018 | ± | 0.006 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 | 50.0 | 1942.11 | 2207.48 | 2100 | ± | 100 | 1800 | ± | 200 | 0.016 | ± | 0.004 |
| 60.0 | 2662.65 | 2905.25 | 2800 | ± | 100 | 2400 | ± | 300 | 0.014 | ± | 0.003 |
|  | | | | | | | | | | | | | | | |
| Qualitative Observations | | | | | | | | | | | | | | | |
| * Catalyst is a finely powdered black solid. * Instant rapid bubbling when the catalyst is released into the prepared H2O2 solution. * Catalyst has poor solubility, mostly remaining solid in the solution as black suspensions. | | | | | | | | | | | | | | | |

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| ***Table-5***: Data and observations for **Iron (III) Oxide** | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Qualitative observations and attempts to collect data   * Catalyst is a finely powdered red solid. * No visual evidence of any reaction occurring after the catalyst is released into the prepared H2O2 solution initially, but tiny bubbles begin to emerge after around 600 seconds. * Catalyst has poor solubility, mostly remaining solid in the solution as red suspensions. * The amount of gas produced by the system in 1800 seconds is not measureable by the gas syringe used, no data could be collected on the prepared H2O2 solution as a result. * An attempt was made to use the undiluted 1 mol dm-3 H2O2 solution with the catalyst, but still yielded no measurable result after 1800 seconds, hence measurement for this catalyst is terminated. |
| Average initial temperature across trials (°C) | 21.3  ±0.2 |
| Average mass of catalyst across trials (grams) | 0.942  ± 0.002 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 |
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| ***Table-6***: Data and observations for **Potassium Iodide**, where the system is constantly **swirled** | | | | | | | | | | | | | | | |
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| Initial conditions and controlled variables, with aggregate error | |  | Raw data | | | | | |  | Processed data – rate of reaction | | | | | |
| Volume of gas *V*  (cm3)  ± 2.5 cm3 instrument error | Time *t* (Seconds) | | | | | Average time *tµ* (Seconds)  with aggregate error | | | Rate *r* (cm3 s-1)  with aggregate error | | |
| Trial 1 | Trial 2 | Trial average  with aggregate error | | |
| Average initial temperature across trials (°C) | 21.1  ± 0.1 | ± 0.01 seconds instrument error | |
| Average mass of catalyst across trials (grams) | 1.012  ± | 10.0 | 9.15 | 8.47 | 8.8 | ± | 0.4 |
| 20.0 | 19.34 | 18.76 | 19.1 | ± | 0.3 | 13.9 | ± | 0.8 | 1.0 | ± | 0.4 |
| Volume of H2O2 solution (dm3) | 200.0  ±0.6 | 30.0 | 31.17 | 29.02 | 30 | ± | 1 | 25 | ± | 1 | 0.91 | ± | 0.2 |
| 40.0 | 43.68 | 40.21 | 42 | ± | 2 | 36 | ± | 3 | 0.8 | ± | 0.2 |
| Concentration of H2O2 solution (mol dm-3) | 0.10  ±0.01 | 50.0 | 56.72 | 52.64 | 55 | ± | 2 | 48 | ± | 4 | 0.8 | ± | 0.2 |
| 60.0 | 67.33 | 67.22 | 67.28 | ± | 0.08 | 61 | ± | 2 | 0.8 | ± | 0.1 |
|  | | | | | | | | | | | | | | | |
| Qualitative Observations | | | | | | | | | | | | | | | |
| * Catalyst is a powdered crystalline white solid. * The catalyst is highly soluble, the solid catalyst dissolves instantly when released into the prepared H2O2 solution, followed by bubbling. * The originally clear and colourless H2O2 solution turns into a clear brown colour after the catalyst is dissolved in it. * Bubbling significantly intensifies after swirling begins. | | | | | | | | | | | | | | | |

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| ***Table-7***: Derived instantaneous initial rate *r0* of different catalysts reacting with the prepared H2O2 solution, with the relevant properties of each catalyst attached. | | | | | | | |
| Catalysts | Derived instantaneous initial rate *r0* (cm3 s-1),  with aggregate error | | | Relevant properties | | | |
| Molar mass  (g mol-1) | Quantity of H2O2 reacted per catalytic cycle per mol of catalyst | Bond dissociation energy (kJ mol-1) | Surface area (qualitative) |
| Manganese (IV) Oxide | 0.41 | ± | 0.09 | 86.94 | 2 | 402 | Powdered |
| Lead (II, IV) Oxide | 2.6 | ± | 0.7 | 685.6 | 6 | 378 | Powdered |
| Potassium Iodide (undisturbed) | 0.31 | ± | 0.08 | 166.0 | 2 | 323 | Dissolved |
| Copper (II) Oxide | 0.003 | ± | 0.001 | 79.55 | 1 | 343 | Powdered |
| Iron (III) Oxide | No data (≈ 0) | | | 159.7 | 2 | 409 | Powdered |