

**Computing the dynamic frictional coefficient μ_d
between wood and steel by measuring the
relationship between the force of friction and mass.**

Research Question: How does changing the mass of the box sliding against a plank affect the force of friction it experiences?

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1 Introduction

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2 Background Information

Theory says dynamic friction is proportional to the normal force. This means that a frictional coefficient exists, which is F_μ/N where N is the normal force.

2.1 Relevant Theory

“The rate limiting reaction is believed to be the initial reaction between hydrogen peroxide and the iron oxides [Miller1995, ValentineWang1998, Miller1999]. Additionally, the results reveal that the decomposition of H_2O_2 follows pseudo-first order kinetics:

$$-\frac{d[\text{H}_2\text{O}_2]}{dt} = k_{\text{app}}[\text{H}_2\text{O}_2] \quad (2.1)$$

and thus:

$$\ln \left(\frac{[\text{H}_2\text{O}_2]}{[\text{H}_2\text{O}_2]_0} \right) = -k_{\text{app}}t \quad (2.2)$$

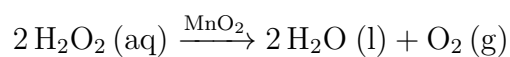
where k_{app} is the apparent first order rate constant, and $[\text{H}_2\text{O}_2]$ and $[\text{H}_2\text{O}_2]_0$ are the concentrations of H_2O_2 in the solution at any time t and time zero, respectively.[Huang]”

The data presented in **Section 4** agrees with theory, that the reaction is pseudo-first order. The aim of this investigation is to measure how k_{app} changes in relation to the amount of catalyst used.

Now a general expression for pressure as a function of time will be mathematically derived from (2.2).

Notation			
$n(\text{H}_2\text{O}_2)$	H_2O_2 in solution at time t	P	Pressure at time t
$n(\text{O}_2)$	O_2 released up to t	P_0	Initial pressure
n_0	Initial H_2O_2 in solution	P_∞	Final pressure
n_{air}	Initial air molecules	V_l	Solution volume
R	Ideal gas constant	V_f	Flask volume
T	Temperature	V_g	$= V_f - V_l$, Gas volume

The catalysed decomposition is



From stoichiometry,

$$n(\text{O}_2) = \frac{n_0 - n(\text{H}_2\text{O}_2)}{2} \implies n(\text{H}_2\text{O}_2) = n_0 - 2n(\text{O}_2).$$

With $[\text{H}_2\text{O}_2] = n(\text{H}_2\text{O}_2)/V_l$ and $PV_g = (n_{\text{air}} + n(\text{O}_2))RT$,

$$n(\text{O}_2) = \frac{PV_g}{RT} - n_{\text{air}}$$

so

$$[\text{H}_2\text{O}_2] = \frac{n_0 + 2n_{\text{air}} - 2PV_g/(RT)}{V_l}$$

At completion $n(\text{H}_2\text{O}_2) = 0$, hence $n_0 + 2n_{\text{air}} = 2P_\infty V_g/(RT)$ and therefore

$$[\text{H}_2\text{O}_2] = \frac{2(P_\infty - P) V_g}{RT V_l}$$

Combining this with the integrated pseudo-first order law

$$-k_{\text{app}}t = \ln \frac{[\text{H}_2\text{O}_2]}{[\text{H}_2\text{O}_2]_0}, \quad [\text{H}_2\text{O}_2]_0 = \frac{n_0}{V_l}$$

and simplifying yields

$$2(P_\infty - P) \frac{V_g}{RT} = n_0 e^{-k_{\text{app}}t}$$

and hence

$$P(t) = P_\infty - \frac{n_0 RT}{2V_g} e^{-k_{\text{app}}t}$$

For brevity define

$$c := \frac{n_0 RT}{2V_g},$$

giving the general form

$$\boxed{P(t) = P_\infty - c e^{-k_{\text{app}}t}}.$$

2.2 Existing Results

For pyrolusite (the primary manganese ore) powder, the highest reported specific rate constant is

$$k_{\text{pyro}} = 0.061 \text{ min}^{-1} \text{ mM}^{-1},$$

measured at room temperature in 200 mL of solution containing 29.4 mM H_2O_2 .**[Do]** This suggests that the rate constant is proportional to the concentration of MnO_2 in solution.

The results obtained in this investigation will be compared with this result. **Hypothesis.** Ideally a proportional relationship between the mass of MnO_2 and k_{app} is observed in this investigation, and the result does not deviate majorly from the above value.

3 Experimental

3.1 Materials & Apparatus

Materials	
33% (v/v) H ₂ O ₂ (aq), diluted to 3.3%	10 ± 0.5 mL per trial
Pure distilled water	20 ± 0.5 mL per trial
Fine MnO ₂ powder	≈ 1g total
Equipment	
220 mL Erlenmeyer flask	Thermometer
20 mL Medical syringe (±0.5 mL)	Electronic scale (±0.001 g)
Vernier Pressure sensor ¹	Rubber stopper
Magnetic stir bar and stir plate	Parafilm

This fit gives the specific rate constant $k_{\text{spec}} \approx 0.00009093 \text{ s}^{-1} \text{ mM}^{-1} = 0.0054558 \text{ min}^{-1} \text{ mM}^{-1}$, which is within an acceptable range of the known $k_{\text{pyro}} = 0.061 \text{ min}^{-1} \text{ mM}^{-1}$ from **Section 2.2**.

3.2 Conclusion

The data support a direct, near-proportional increase of the apparent first-order rate constant k_{app} with suspended MnO₂ concentration. This matches the general expectation that more active surface yields faster reaction, but the measured specific rate is lower than literature ($0.061 \text{ min}^{-1} \text{ mM}^{-1}$); plausible causes include incomplete O₂ capture (leakage, connector losses), variable effective surface area (agglomeration or settling of powder), the initial connection artifact, and instrument limits (pressure sensor accuracy, uncertain V_g). These uncertainties (notably $V_l \pm 3.3\%$ and sensor $\pm 2 \text{ kPa}$) moderately affect k_{app} and explain observed scatter and the anomalously low 0.05 g point, so quantitative agreement

with literature is tentative though the trend is robust.

Methodological limitations with meaningful impact: reliance on headspace pressure rather than direct concentration assays, imperfect seals, limited replicates per mass and a narrow mass range, and possible temperature/stirring inconsistencies. Strengths include a clear theoretical derivation linking $P(t)$ to $[\text{H}_2\text{O}_2]$ and continuous high-frequency data collection.

Realistic, relevant improvements: use pressure-rated fittings or water-displacement gas collection; immobilize catalyst or better disperse powder; increase replicate number and mass range; directly assay $[\text{H}_2\text{O}_2]$ (titration or spectrophotometry) for cross-validation; calibrate sensor and measure V_g precisely. With these changes the proportional relationship can be tested more reliably and quantitative agreement improved.