23rd IYPT Problem : Steel Balls

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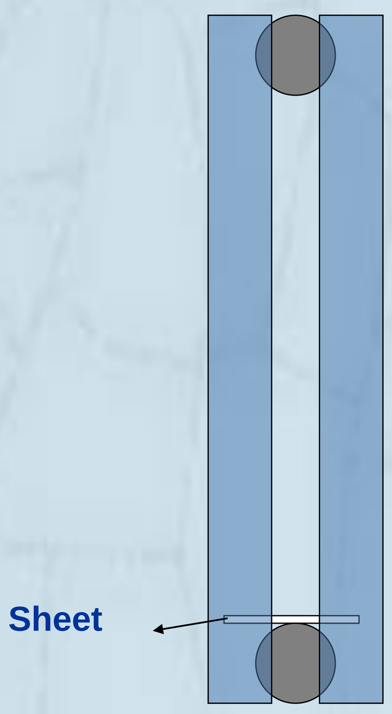
Abstract

Colliding two large steel balls with a thin sheet of material (e.g. paper) in between may "burn" a hole in the sheet. Investigate this effect for various materials.

We tried different materials in this experiment in order to investigate the physical phenomenon during the steel ball collision. For thin papers, we can burn a hole by collision. For plastic materials, we can melt the sheet, but not necessarily create a hole. For metallic sheets, like copper and aluminum foils, interesting circular ripples were observed. The steel ball collision can be simplified as an adiabatic process, during which the work done by steel balls is transferred to heat. Therefore the temperature at collision area is significantly increased, resulting in the paper burning or the melting of thin sheets.

Experimental Setup   vertical collision



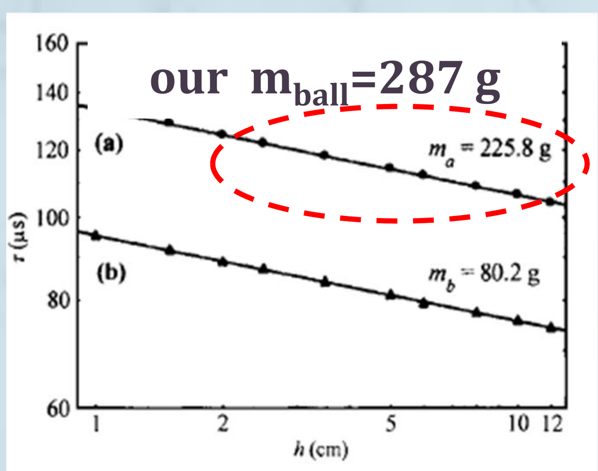
Theory & Discussion

Duration Δt = ?

1. Our high speed video: 230 μs/frame

$\Rightarrow \Delta t < 230\ \mu s$

2. From reference



R. Hessel, A. C. Perinotto, R. A. M. Alfaro, and A. A. Freschia, Am. J. Phys. 74 3, 176 (2006).

We can conclude : $\Delta t < 230\ \mu s$

Work ΔW=?

Pressure P > 1.2 x 10^9 Nt/m^2
Collision Area $A=\pi r^2 \sim 2\times10^{-6}$ m^2
Thickness of sheet $\Delta d = 10^{-4}$ m

$$\Delta W = P\times\Delta V = P\times(A\times\Delta d) > 3.9\times10^{-1}(J)$$

Conducted heat ΔQ=?

	σ
Air	0.026
Al	237
Cu	401
Fe	80.4
Steel	46
Water	0.61
Wood	0.11

$$\frac{\Delta Q}{\Delta t} = \sigma\times A\times\Delta T$$

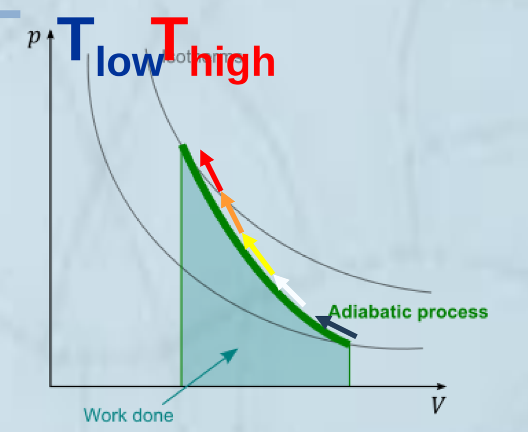
$\Delta T <$ 1000 ℃
$A=\pi r^2 \sim 2\times10^{-6}$ m^2

$$\Delta Q < 401\times(2\times10^{-6})\times1000\times2.3\times10^{-4} \sim 1.8\times10^{-4}(J)$$

Adiabatic process!!

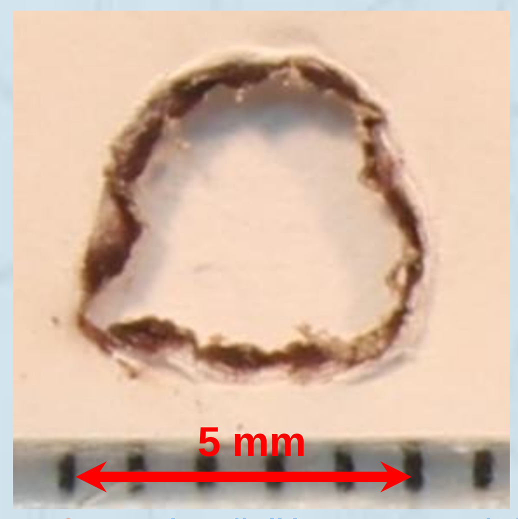
- Work done during collision $\Delta W > 3.9\times10^{-1}$ (J)
- Heat conducted during collision : $\Delta Q < 2.9\times10^{-4}$ (J)

$\Delta W >> \Delta Q \Rightarrow$ Adiabatic process

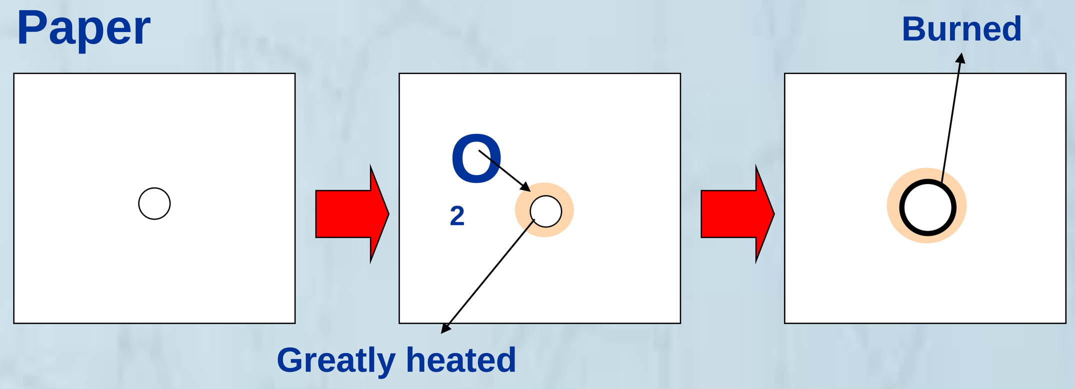


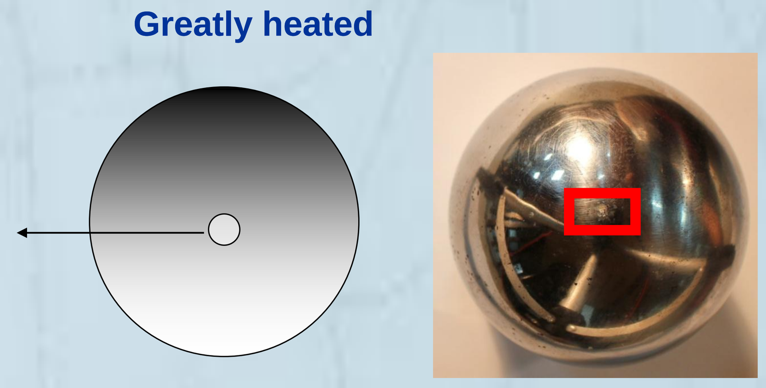
Experimental Results

1. Paper (Burning point: 130°~232°C)

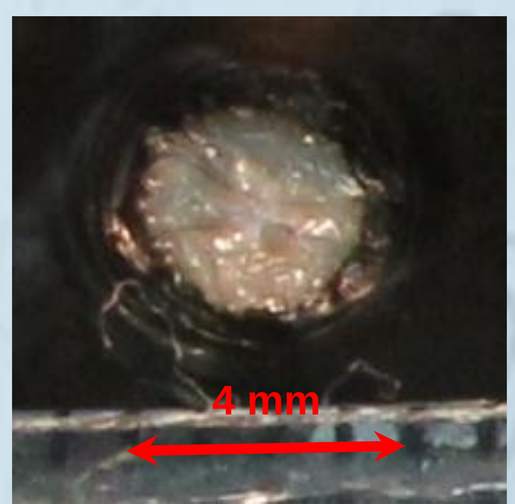


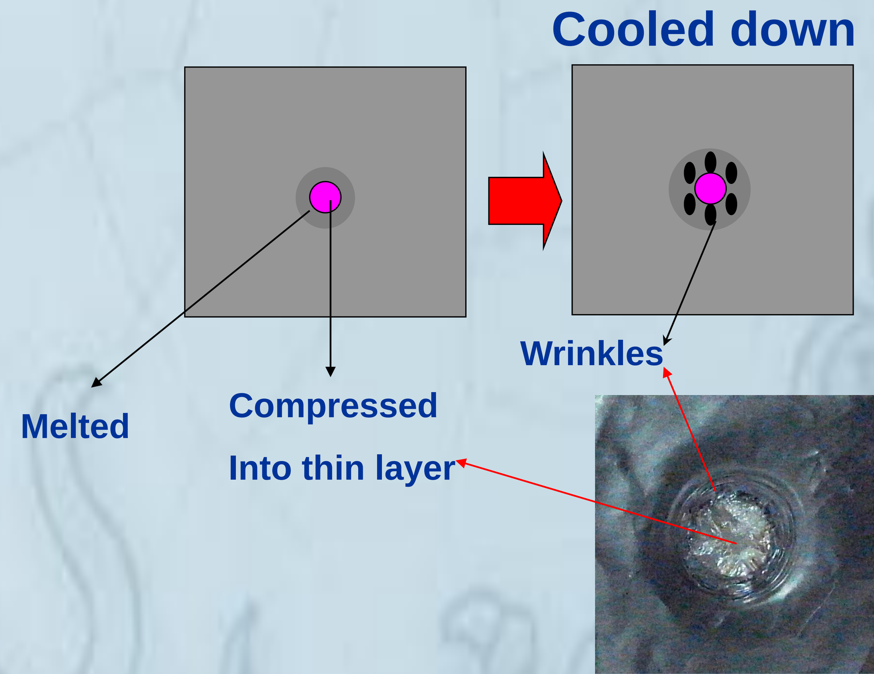
Reference: http://wiki.answers.com/Q/What_is_the_Burning_point_of_paper



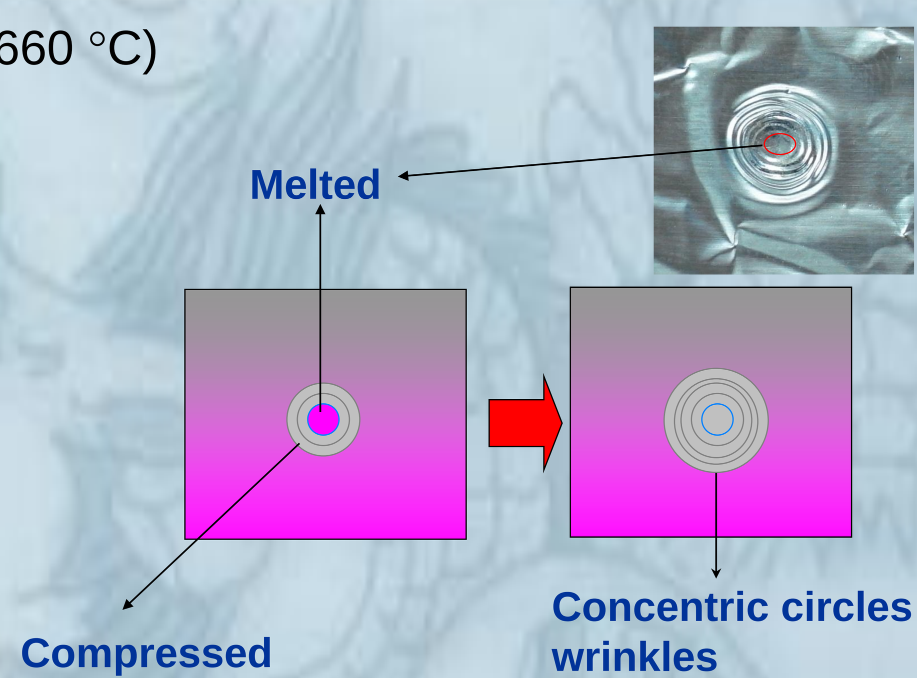


2. Plastic (Melting Point: 106~114℃)
(Soften temperature: 80~98℃)



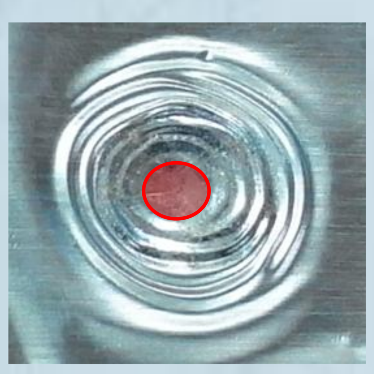


3. Aluminum foil (Melting point: 660 °C)

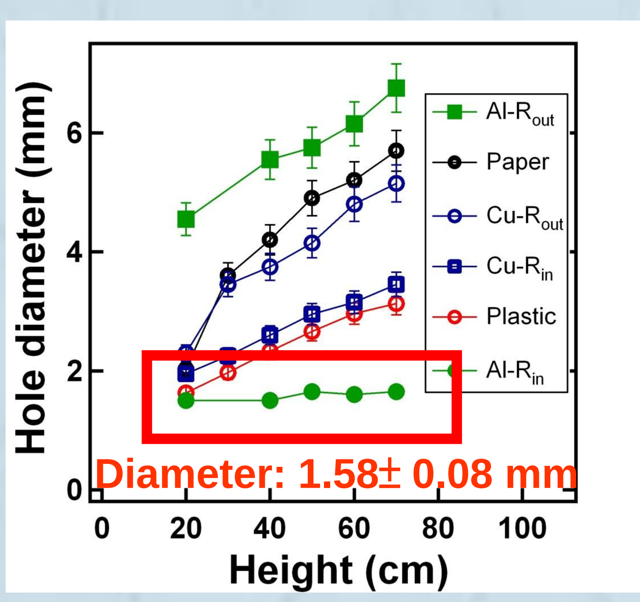


Collision area A=?

Estimate A from the melted Al foil .



Al foil



Average pressure P = ?

$$P = \frac{F}{A} = \frac{\Delta p}{\Delta t}\times\frac{1}{A} \qquad 2p_o = 2m\sqrt{2gH} > \Delta p > m\sqrt{2gH} = p_o$$

m=287 g, H=50 cm, g=9.8 m/s^2, A< π(0.8mm)^2 , Δt < 230 μs

$$P > \frac{0.287\times\sqrt{2\times9.8\times0.5}}{2.3\times10^{-4}}\times\frac{1}{0.0008^2\times3.14} = 1.9\times10^9(\frac{Nt}{m^2})$$

$$P \geq 1.9\times10^4\,atm$$

Conclusion

Height: Diameter of holes increases as height increases

Collision Area: Melting or Burning

Adiabatic Process is the main reason holes are burned because:
Δt is small, Area is small, abd Pressure is high

$\Rightarrow \Delta T$ is high