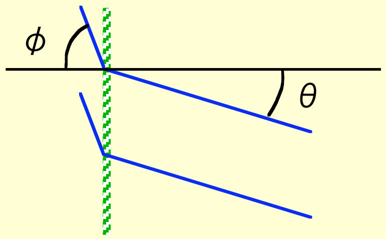
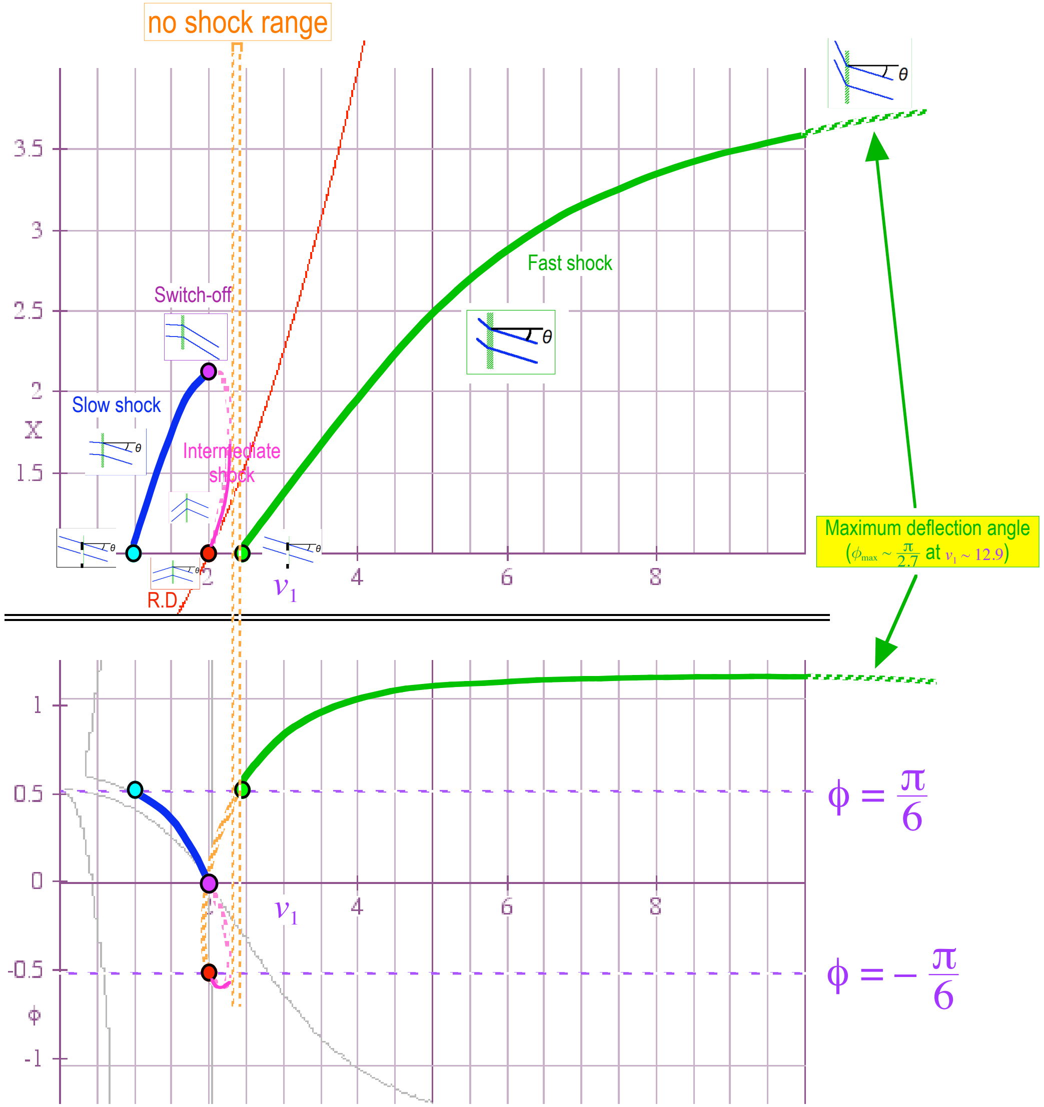
Angle relation (θ, ϕ)



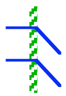
$\gamma = \frac{5}{3}, v_{A1} = 2, c_{s1} = 1 \; (\Rightarrow \beta_1 = 0.3)$

$\theta = \frac{\pi}{6}$



Fast shock $v_1 \geq \sqrt{X}\, v_{A1}$
Slow shock $v_1 \leq v_{A1}$
Rotational discontinuity $v_1 = v_{A1}$

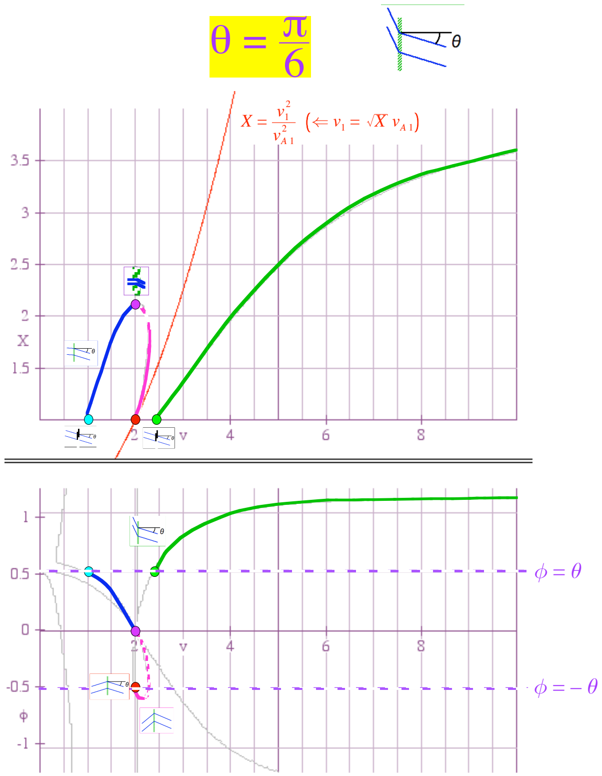
Switch-off shock with $v_1 = v_{A1}$
$\left(v_{x1} = \frac{B_{x1}}{\sqrt{\mu \rho_1}} = \frac{B_{x2}}{\sqrt{\mu \rho_1}}\right)$



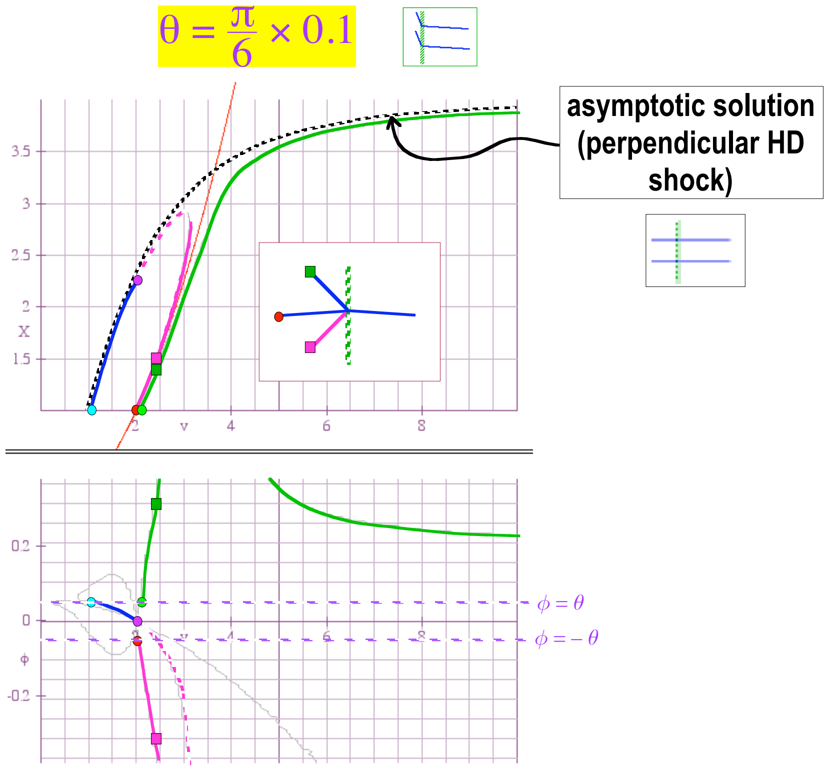
Transition from normal fast shock to switch-on shock

$\gamma = \frac{5}{3}, \beta = 0.3, v_{A1} = 2, c_{s1} = 1$

$\theta = \frac{\pi}{6}$



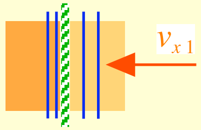
$\theta = \frac{\pi}{6} \times 0.1$



Several limiting cases of oblique MHD shock

Fast shock...

when $\theta = \frac{\pi}{2}$, perpendicular MHD shock

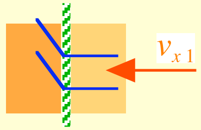


$$1 < X(v_1) < \frac{\gamma+1}{\gamma-1}$$

no upper limit of v_{x1}

when $\theta \to 0$ (low-beta case), switch-on shock

$v_{A1} < v_{x1} \le v_{A1}\sqrt{\frac{\gamma + 1 - 2\,c_{s1}^2/v_{A1}^2}{\gamma - 1}}$

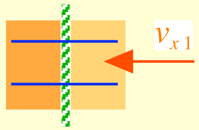


$$1 < X(v_1) \le \frac{\gamma + 1 - 2\,c_{s1}^2/v_{A1}^2}{\gamma - 1}$$

low-beta

when $\theta = 0$, perpendicular HD shock

In a low-beta case with $v_{x1} > \sqrt{X}\, v_{A1}$, it becomes perpendicular HD shock.
In a high-beta case with $v_{x1} > c_{s1} > v_{A1}$, it becomes perpendicular HD shock.



$$\frac{\gamma + 1 - 2\,c_{s1}^2/v_{A1}^2}{\gamma - 1} < X(v_1) < \frac{\gamma+1}{\gamma-1}$$

low-beta

no upper limit of v_{x1}

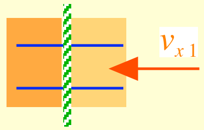
$$1 < X(v_1) < \frac{\gamma+1}{\gamma-1}$$

high-beta

Slow shock...

when $\theta = 0$ (low-beta case), perpendicular HD shock

In a low-beta case with $v_{A1} > v_{x1} > c_{s1}$, it becomes perpendicular HD shock.



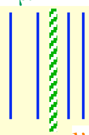
$$1 < X(v_1) \le \frac{\gamma + 1}{\gamma - 1 + 2c_{s1}^2/v_{A1}^2}$$

low-beta

Tangential discontinuity...

simple boundary between two regions where total pressure (magnetic pressure + gas pressure) is the same

$$p_1 + \frac{B_1^2}{2\mu} = p_2 + \frac{B_2^2}{2\mu}$$



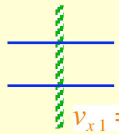
$v_{x1} = 0,\ v_{x2} = 0$

X is variable

Contact discontinuity...

simple boundary between two regions where density and temperature take different values

$p_1 = p_2$



$v_{x1} = 0,\ v_{x2} = 0$

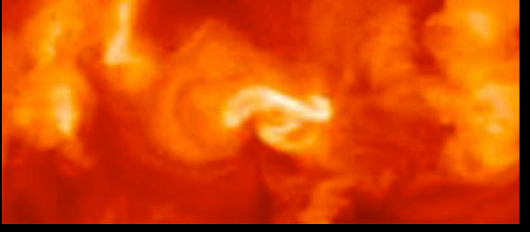
X is variable

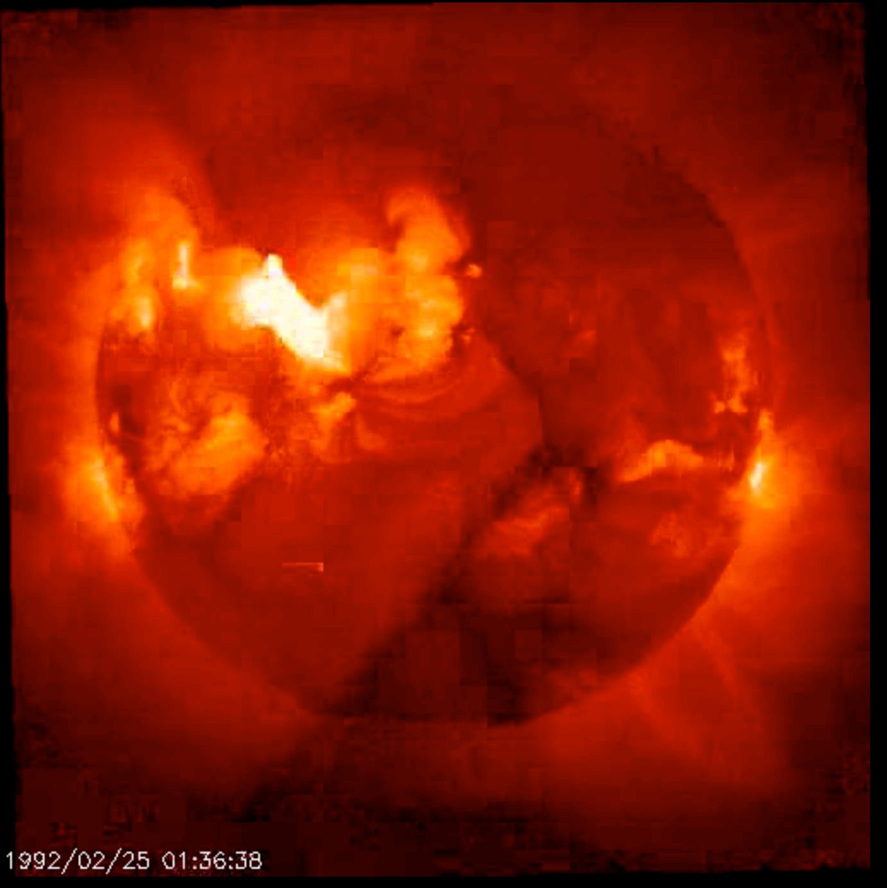
Magnetic Reconnection

— fast magnetic energy-releasing process —

Solar flare...

explosive phenomenon which **rapidly releases free magnetic energy** stored in the corona





Observed by Yohkoh

Evolution of magnetic field

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\nabla \times \boldsymbol{E}$$

evolution caused by the rotation of electric field