Harvard Astronomy 201b: Shock De-jargonification

	NON-RADIATIVE (no radiative cooling post-shock)		RADIATIVE (treats cooling of post-shock gas)	
	"**viscous**" shock	*a fictitious, truly* "**adiabatic**" shock	*poorly named!* "**isothermal**" shock	"**radiative**" shock
continuity equation used (conservation of **mass**)	✔	✔	✔	✔
conservation of **momentum** equations used	✔	✔	✔	✔
conservation of **energy** equations used	✔	✔	✘	✘
entropy conserved ("isentropic" conditions)	✘	✔	✘	✘
energy loss via **radiative cooling**	✘	✘	✔	✔
Comments	a **"strong" shock** is one of these where Mach# >>1	*This is impossible! Shocks are irreversible processes, so entropy will go up.*	The "isothermal" part refers to the post-radiative-cooling T = to original T.	cooling due to radiation

From Frank **Shu**, in "The Physics of Astrophysics", Volume 2, p. 226 (emphasis is AG's):

> "Let me here comment on the term "**adiabatic**." The word as commonly applied by astronomers to **nonradiative** shock waves is a pernicious misnomer and should be avoided if possible. **Adiabatic** does not mean "energy-conserving," but "**entropy-conserving**." **Entropy** represents precisely the quantity that is **not preserved in a strong shock**. A strong shock wave sends a violent *irreversible* perturbation through the system; in no sense can such a process be regarded as "adiabatic."

From Bruce **Draine** in "Physics of the Interstellar and Intergalactic Medium," p. 402:

> "...Suppose now that the hot gas cools by emitting radiation, cooling until it reaches a temperature $T_3=T_1$. A shock where the postshock gas cools to the initial temperature T_1 is sometimes referred to as an **isothermal shock**. This is misleading – the gas temperature does *not* remain constant."

From Shu, the Physics of Astrophysics, p. 215 and p. 228 (note typo u_2/u_1 should be u_1/u_2 on p. 215, fixed below)

For a non-radiative, viscous shock, the Rakine-Hugoniot Jump Conditions give, for a perfect gas:

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)M_1^2}{(\gamma+1)+(\gamma-1)(M_1^2-1)} = \frac{u_1}{u_2} \qquad (15.35)$$

$$\frac{P_2}{P_1} = \frac{(\gamma+1)+2\gamma(M_1^2-1)}{(\gamma+1)}, \qquad (15.36)$$

$$\frac{T_2}{T_1} = \frac{[(\gamma+1)+2\gamma(M_1^2-1)][(\gamma+1)+(\gamma-1)(M_1^2-1)]}{(\gamma+1)^2M_1^2}. \qquad (15.37)$$

(see graphs below)

For a radiative ("isothermal") shock, the jump conditions are:

Equations (16.33) can often be approximated by the isothermal jump condition

$$T_3 = T_1. \qquad (16.34)$$

With a constant isothermal sound speed,

$$a_T = (kT/m)^{1/2}, \qquad (16.35)$$

we may easily solve the remaining relations to obtain the so-called "isothermal shock" jump conditions,

$$u_3u_1 = a_T^2 \qquad \text{with} \qquad \frac{\rho_3}{\rho_1} = \left(\frac{u_1}{a_T}\right)^2. \qquad (16.36)$$

(see graphs below)

Google spreadsheet calculating these ratios is here.

One derivation of these conditions can be found on Wikipedia, here.

"ISOTHERMAL" Shock

(Radiatively Cools in Transition Layer so that Final T=Original T, after being HOT in-between!)

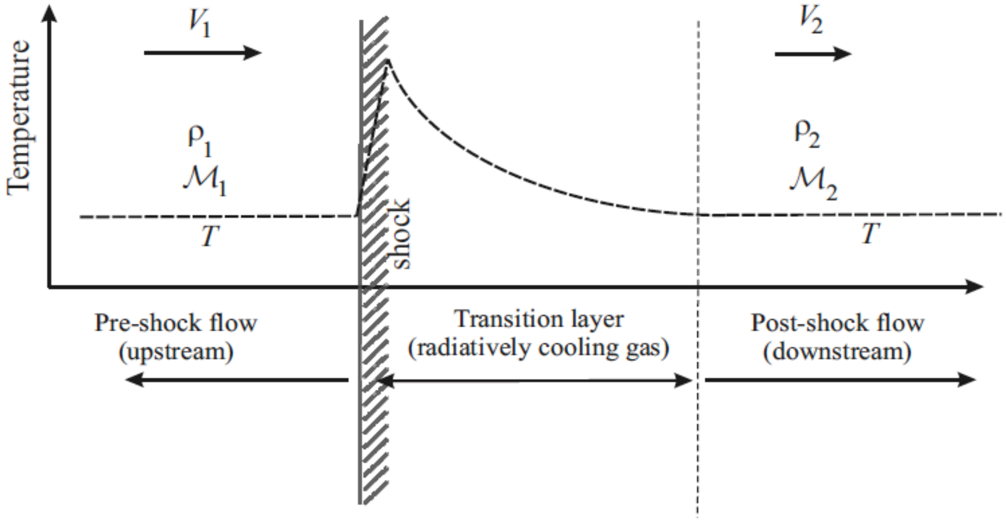


Figure 4: *A schematic representation of the behaviour of the gas temperature* T *(dashed curve) in an isothermal shock. In this figure, the gas flows from left to right. First the incoming gas encounters in a true shock, where (as in any shock) the temperature, density and pressure rise sharply. Then the excess thermal energy per particle is radiated away as the gas cools in a transition layer behind the shock. The cooling stops when the temperature returns to the pre-shock value. The downstream state you are asked to calculate in this assignment corresponds to the state of the gas behind this transition layer.*

From 2011 version of *http://www.astro.uu.nl/~achterb/aigd/set5.pdf*

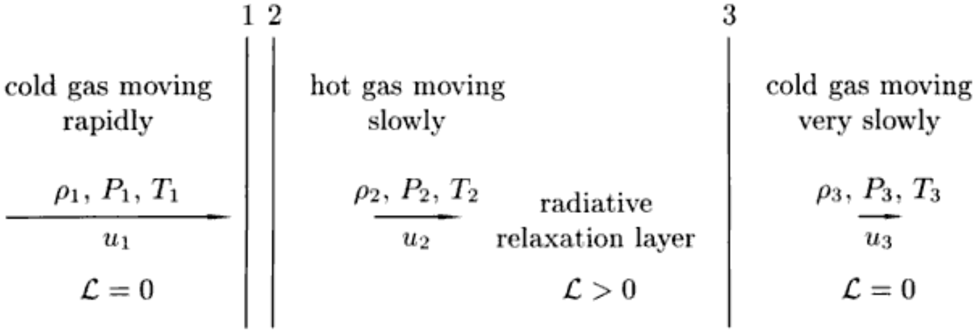


FIGURE 16.8

Schematic regions of interest in a radiative shock. Ahead of a normal viscous shock front lies cold, rapidly moving gas (in the frame of rest of the shock front). A sudden deceleration, compression, and heating of the gas occurs in the viscous transition layer, 1 to 2. Downstream from the viscous layer, the shocked gas is thrown badly out of thermal equilibrium and radiates profusely. The radiative cooling, assumed here to occur under optically thin conditions, lowers the temperature until the gas eventually reattains radiative balance at point 3.

From Shu, The Physics of Astrophysics, Volume 2, p. 227. (Google Books Link)

“ISOTHERMAL” Shock

(Radiatively Cools in Transition Layer so that Final T=Original T, after being HOT in-between!)

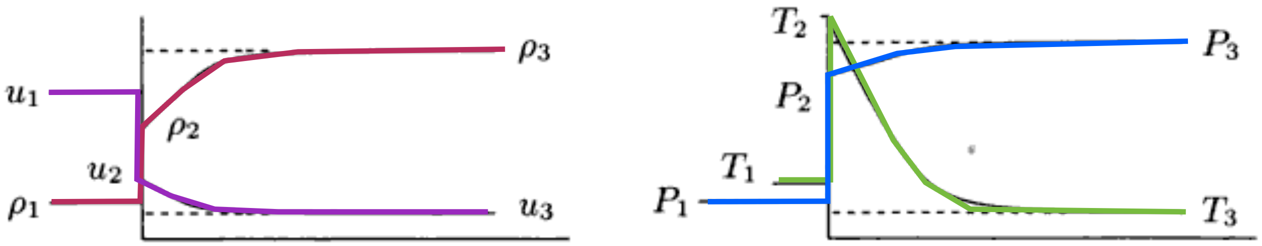


FIGURE 16.9
Schematic depiction of the variation of the velocity and density (first panel), and of the pressure and temperature (second panel), in a radiative shock.

From Shu, The Physics of Astrophysics, Volume 2, p. 228 (colorization added; Google Books Link)

For reference, the **equivalent picture for a viscous shock** looks like this (note that I’ve had to flip Shu’s picture backward to make it consistent!)

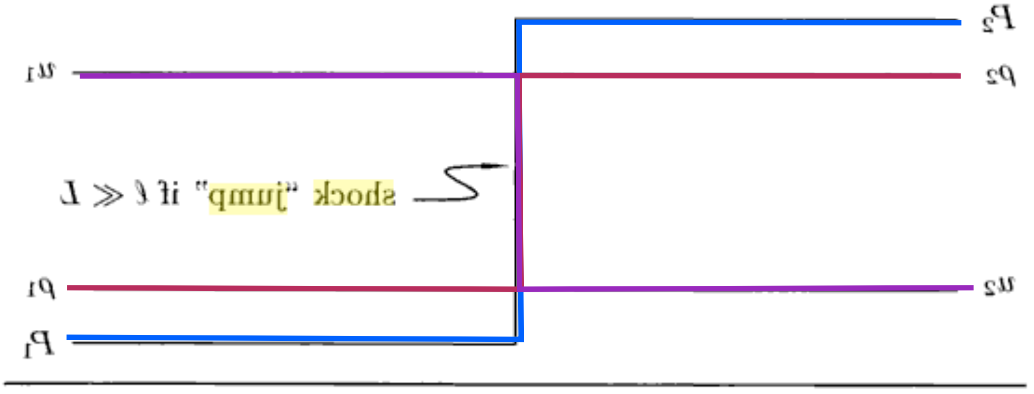


FIGURE 15.9
On macroscopic scales, shock transitions may be approximated as single discontinuous jumps.

Based on Shu, The Physics of Astrophysics, Volume 2, p. 214 (colorization added; Google Books Link)

Viscous Shocks

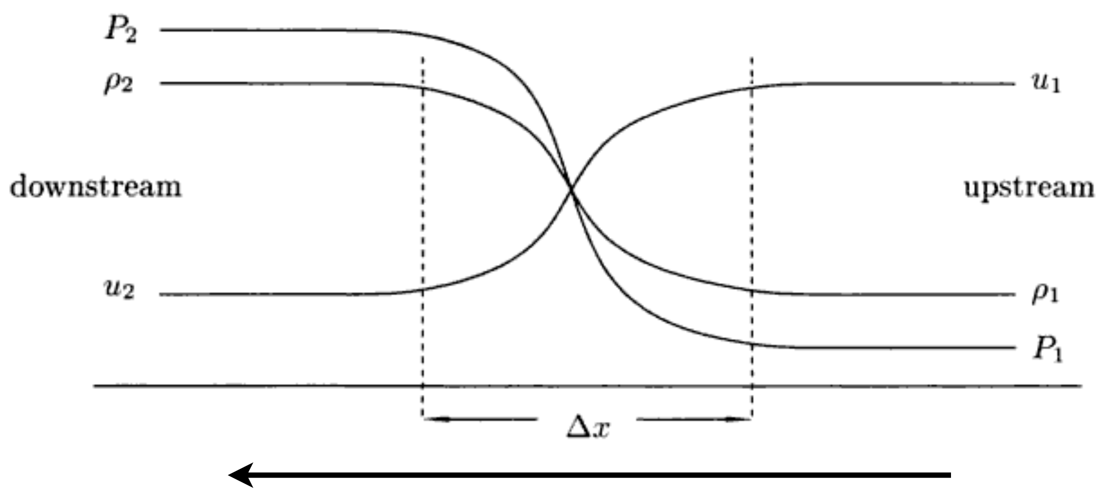


FIGURE 15.8
Across a viscous shock, the pressure and density increase and the velocity decreases as the gas flows from the upstream state to the downstream state. The transition is made in a characteristic distance Δx that equals a few mean free paths ℓ for the elastic scattering of the gas particles.

From Shu, The Physics of Astrophysics, Volume 2, p. 213. (Google Books Link)

For reference, the **approximation (where Δx very small)** looks like this:

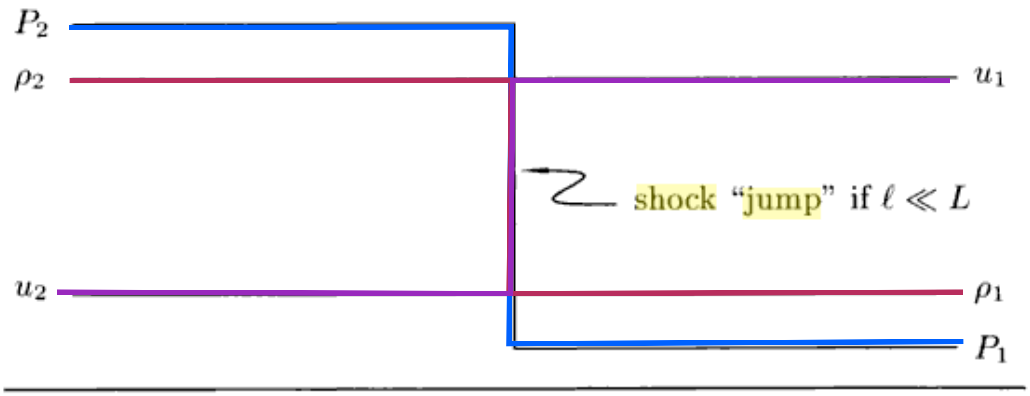
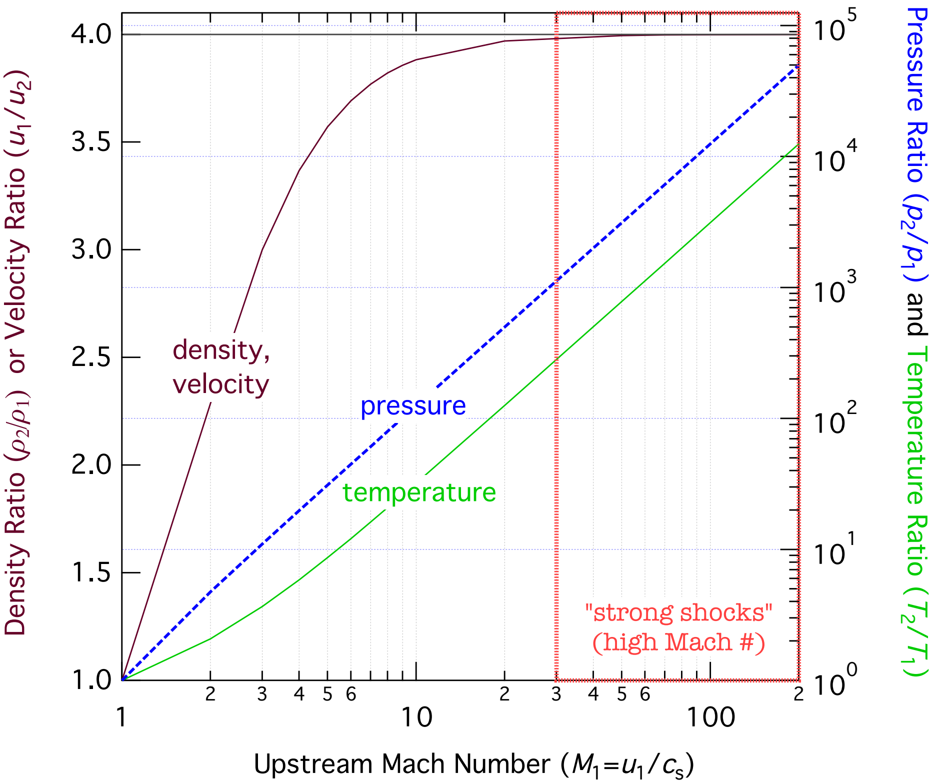


FIGURE 15.9
On macroscopic scales, shock transitions may be approximated as single discontinuous jumps.

Based on Shu, The Physics of Astrophysics, Volume 2, p. 214 (colorization added; Google Books Link)

Notice that the y-axis is scaled differently on the left here... density jump maxes out at 4.

Behavior of Non-Radiative Shocks **Viscous Shocks**



Behavior of Radiative Shocks **Radiative Shocks**