

Sept. 20 2002: Lecture 8:

## Stored Energy in Solids, First Law for Fluids

### Last Time

#### Linear Isotropic and Anisotropic Material Properties

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#### Chemical Work

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#### Elastic Work

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### Summary: Forms of Work in the First Law

From the the first law of thermodynamics

$$dU = dq + dw \quad (8-1)$$

We identified the work associated with various types of physical processes. For the case of a magnetic and polarizable solid we have:

$$dw = V \vec{E} \cdot d\vec{D} + V \vec{H} \cdot d\vec{B} + V \sigma_{ij} d\epsilon_{ij} + \dots + \dots \text{ as many work terms as required to account for adiabatic energy changes} \quad (8-2)$$

The extra terms could include chemical work, work to add or subtract charge from a body, potential energy in a gravitational field, etc.

For the special case of a non-polar, non-magnetic fluid, that cannot change its composition, the work is simply:

$$dw = -PdV \quad (8-3)$$

Systems that have Equation 8-3 as the *only* type of work term will be called *simple pure fluids*.

Questions: Why does the  $V$  term appear in front of the terms in Eq. 8-2 and *not* in front of Eq. 8-3? Why is there a “minus sign difference”? Could Eq. 8-3 be modified so it also have a “reference volume term” out front?

### Work performed by Simple Fluids

The incremental work performed by a simple pure fluid is  $dw = PdV$ , so  $dU = dq - PdV$ . Recall that  $U$  is a state function:

Question: Can we simply integrate  $dw$  between two states, say “State A” and “State B”, and identify the work done by the body?

$$\int_{\text{State A}}^{\text{State B}} dw \stackrel{?}{=} w(\text{State B}) - w(\text{State A}) \quad (8-4)$$

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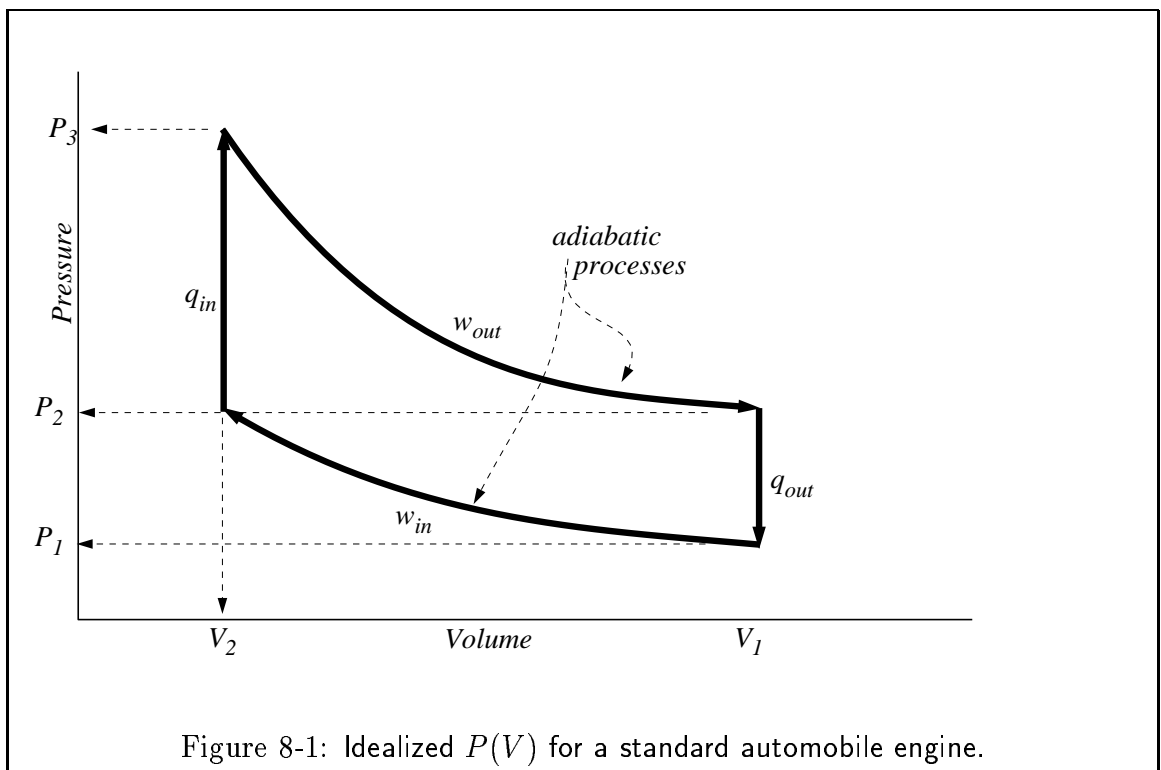


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If Equation 8-4 were true, then for any “work cycle” (i.e., one that returns to its initial state—the initial state and the final state are the same.)

$$\oint dw \stackrel{?}{=} 0 \quad (8-5)$$

An idealized automobile engine can be represented by the following  $P(V)$ -path:




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$$\oint dw = - \oint PdV \neq 0 \quad (8-6)$$

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$dw$  is sometimes called “not a perfect differential” because of this property. It simply means that you need even more information to integrate it—namely the path:  $\int dw$  is “path dependent”.

Furthermore, the idealization in Figure 8-1 is a somewhat misleading.

It is easy to specify what the volume is in such a system, but what about the pressure,  $P$ , just after the beginning of the “spark?” The pressure is not uniform throughout the piston

cylinder and cannot be represented by a point—so the curve cannot be represented by a series of points.

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The idealization in Figure 8-1 introduces the topic of *reversibility*. (Sometimes, the terms *quasi-equilibrium* or *quasi-static* are used, they are effectively synonyms for reversible processes).

During a quasi-static process, all of the intensive variables are approximated as uniform; so it is possible to use one value and represent it on a graph such as Figure 8-1. However, it is important to realize that the quasi-static case is a *limiting* case that can be realized only if the system moves slowly enough to that all the intensive variables can adjust to their equilibrium values. This would be an efficient automobile engine, but the upper limit of its horsepower would be zero.

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