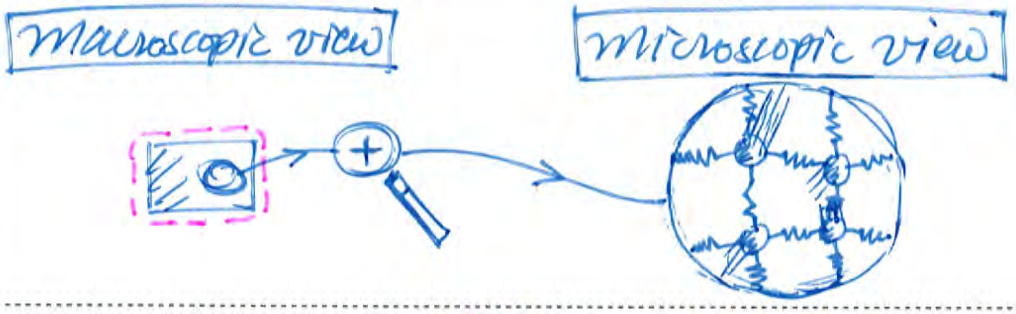
E5

**Title** Internal energy

**Ingredients**

**Sketch**




**At/Through** t

**Owner** System with macroscopic features and microscopic features

| Quantity | Variable | Giver |
|---|---|---|
| Total kinetic energy of macro. features | $\Sigma K_{MAC}$ | |
| Total potential energy of macro. features | $\Sigma U_{MAC}$ | |
| Total kinetic energy of all features | $\Sigma K_{MAC+MIC}$ | |
| Total potential energy of all features | $\Sigma U_{MAC+MIC}$ | |
| Total internal energy | $\Sigma U_{INT}$ | |

**Recipe**

**Diagram the relationship**

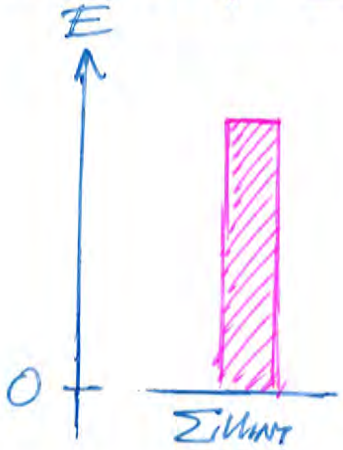
(No memorized defining formula).

$\Sigma U_{INT}$

$\Sigma K_{MAC} + \Sigma U_{MAC} \rightarrow \Sigma K_{MAC+MIC} + \Sigma U_{MAC+MIC}$

**Graphically present quantities**

Internal energy bar chart




**Mathematical relationship**

(No memorized defining formula).

$$\Sigma K_{MAC} + \Sigma U_{MAC} + \Sigma U_{INT} = \Sigma K_{MAC+MIC} + \Sigma U_{MAC+MIC}$$

Page E5
Title: Internal energy

The top half of this sheet consists of an "**Ingredients**" section with a row labeled "Sketch", a row labeled "At/Through", a row labeled "Owner", a row labeled "Quantity", a row labeled "Variable", and a row labeled "Giver."

Sketch: Title at left: "Macroscopic view". A block is surrounded by a dashed system bubble. A circular outline indicates a small portion of the block. A path connects the circular outline, through an icon of a magnifying glass, to a larger circle under the title at right, "Microscopic view". The larger circle shows a magnified view of internal components of the block, namely atomic centers represented as little spheres, and chemical bonds represented by springs. The atomic centers are vibrating, as indicated by whooshies of various lengths and directions, and the chemical bonds have various extents of deformation from their equilibrium shapes, as indicated by the variety of amounts of compression and stretch among the springs.

Remaining rows of Ingredients section are used for a flowchart illustrating the following:
The Owner is a System with macroscopic features and microscopic features. At time t, the macroscopic features of the system own the Quantity Total kinetic energy of macroscopic features denoted by the Variable Sigma-K-sub-MAC. At time t, the macroscopic features also own the Quantity Total potential energy of macroscopic features denoted by the Variable Sigma-U-sub-MAC. At time t, the System, including both its macroscopic and microscopic features, owns the Quantity Total kinetic energy of all features denoted by the Variable Sigma-K-sub-MAC+MIC. At time t, the System, including both its macroscopic and microscopic features, also owns the Quantity Total potential energy of all features denoted by the Variable Sigma-U-sub-MAC+MIC. Finally, at time t, the System, including both its macroscopic and microscopic features, owns the Quantity Total internal energy denoted by the Variable Sigma-U-sub-INT.

The bottom half of this sheet consists of a "**Recipe**" section with a row labeled "Diagram the relationship", a row labeled "Graphically present quantities", and a row labeled "Mathematical relationship".

Diagram the relationship
Parenthetic note: No memorized defining formula
A flowchart arrow shows that the sum of the total kinetic energy of macroscopic features and the total potential energy of macroscopic features Sigma-K-sub-MAC + Sigma-U-sub-MAC contributes to the sum of the Total kinetic energy of all features and the total potential energy of all features Sigma-K-sub-MAC+MIC + Sigma-U-sub-MAC+MIC. Another arrow shows that the total internal energy Sigma-U-sub-INT also contributes to the sum of the Total kinetic energy of all features and the Total potential energy of all features Sigma-K-sub-MAC+MIC + Sigma-U-sub-MAC+MIC.

Graphically present quantities
Internal energy bar chart
Plot E on the vertical axis. Draw a tickmark labeled 0. At the height of this tickmark, draw a horizontal segment to the right, labeled underneath as Sigma-U-sub-INT. From and extending upward from this labeled segment, draw a shaded rectangular bar.

Mathematical relationship
Parenthetic note: No memorized defining formula
Sigma-K-sub-MAC + Sigma-U-sub-MAC + Sigma-U-sub-INT = Sigma-K-sub-MAC+MIC + Sigma-U-sub-MAC+MIC