the first law of thermodynamics
Indice Modulo

Strategies - Before

- Prerequisites
- Linking to Previous Knowledge and Predicting con questionari basati su stimoli relativi alle conoscenze pregresse e alle ipotesi riguardanti i contenuti da affrontare
- Italian/English Glossary

Strategies – During

- Video con scheda grafica
- Keywords riferite al video attraverso esercitazioni mirate
- Conceptual Map

Strategies - After

- Esercizi:
  - Multiple Choice
  - Matching
  - True or False
  - Cloze o Completion
  - Flow Chart
  - Think and Discuss

- Summary per abstract e/o esercizi orali o scritti basati su un questionario e per esercizi quali traduzione e/o dettato

- Web References di approfondimento come input interattivi per test orali e scritti e per esercitazioni basate sul Problem Solving

Answer Sheets
1

Strategies Before
Prerequisites

**Basic Concepts of Physics**

- Definition of a work of a force
- Definition of pressure
- Definition of Volume
- Definition of Kinetic Energy
- Definition of Potential Energy
- Definition of Mechanical Energy
- Units of Energy in the I.S.
- Concept of a state function

**Thermodynamics**

- Definition of thermodynamic system
- Definition of Temperature
- Concept of function of state
- Concept of Transformation and its representation on the PV plane
- Isobaric, isochoric, isothermal and adiabatic transformations

**First Law of Thermodynamics**
2

**Strategies Before**

*Linking to Previous Knowledge and Predicting*

- What is the definition of pressure?
- What is the definition of work?
- How can the work of pressure forces be calculated?
- What do we mean by a thermodynamic system?
- What are the functions of state of a thermodynamic system?
- What do we mean by thermodynamic transformation?
- What are the characteristics of isothermal, isochoric, isobaric and adiabatic transformations?
- How do you represent on the PV plane, isothermal, isochoric, isobaric and adiabatic transformations?
- What are the characteristics of a perfect gas?
- What is meant by state function?
### 3
**Strategies Before**
*Italian/English Glossary*

<table>
<thead>
<tr>
<th>Italian</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adiabatica</td>
<td>Adiabatic</td>
</tr>
<tr>
<td>Ambiente esterno</td>
<td>External Environment</td>
</tr>
<tr>
<td>Atomo</td>
<td>Atom</td>
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<tr>
<td>Calore</td>
<td>Heat</td>
</tr>
<tr>
<td>Ciclo</td>
<td>Cycle</td>
</tr>
<tr>
<td>Conservazione</td>
<td>Conservation</td>
</tr>
<tr>
<td>Energia cinetica</td>
<td>Kinetic energy</td>
</tr>
<tr>
<td>Energia interna</td>
<td>Internal energy</td>
</tr>
<tr>
<td>Energia potenziale</td>
<td>Potential energy</td>
</tr>
<tr>
<td>Energia potenziale di legame</td>
<td>Potential Energy of bond</td>
</tr>
<tr>
<td>Gas perfetto</td>
<td>Perfect gas</td>
</tr>
<tr>
<td>Grandezza di Stato</td>
<td>Function of state/state quantities</td>
</tr>
<tr>
<td>Irreversibile</td>
<td>Irreversible</td>
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<tr>
<td>Isobara</td>
<td>Isobaric</td>
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<tr>
<td>Isocora</td>
<td>Isochoric</td>
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<tr>
<td>Isoterma</td>
<td>Isothermal</td>
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<tr>
<td>Lavoro</td>
<td>Work</td>
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<tr>
<td>Macchina di Carnot</td>
<td>Carnot engine</td>
</tr>
<tr>
<td>Macchina Termica</td>
<td>Heat Engine</td>
</tr>
<tr>
<td>Molecole</td>
<td>Molecules</td>
</tr>
<tr>
<td>Pressione</td>
<td>Pressure</td>
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<tr>
<td>Quasi-Statica</td>
<td>Quasi-Static</td>
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<tr>
<td>Rendimento</td>
<td>Performance</td>
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<tr>
<td>Reversibile</td>
<td>Reversible</td>
</tr>
<tr>
<td>Scambi</td>
<td>Exchanges</td>
</tr>
<tr>
<td>Sistema di raffreddamento</td>
<td>Cooling system</td>
</tr>
<tr>
<td>Sistema termodinamico</td>
<td>Thermodynamic system</td>
</tr>
<tr>
<td>Stato di equilibrio</td>
<td>Equilibrium state</td>
</tr>
<tr>
<td>Temperatura</td>
<td>Temperature</td>
</tr>
<tr>
<td>Termodinamica</td>
<td>Thermodynamics</td>
</tr>
<tr>
<td>Trasformazione</td>
<td>Transformation</td>
</tr>
<tr>
<td>Variazioni/cambiamenti</td>
<td>Variation / Changes</td>
</tr>
</tbody>
</table>
1) Circle which of the following words represent functions of state:


2) Circle which of the following quantities are in the formulation of the first law of thermodynamics:

Strategies During
Conceptual Map

Complete the conceptual map using the following words:

- Energy potential bond
- Thermodynamic cycles
- Kinetic energy of molecules
- Irreversible
- Transformations
- Heat engines

the first law of thermodynamics
6 Strategies After Multiple Choice

1) Thermodynamics studies the transformations of:
   a. heat into mechanical energy
   b. mechanical energy into heat
   c. heat energy into chemical energy
   d. kinetic energy into potential energy

2) Heat is:
   a. a fluid that is transmitted from hot bodies to cold bodies
   b. a form of energy in transit
   c. the internal energy of a body
   d. the temperature of a body

3) A heat engine is a device able to transform:
   a. work into heat
   b. potential energy into kinetic energy
   c. chemical energy into heat
   d. heat into work

4) The internal energy of a system depends:
   a. only on the kinetic energy of molecules
   b. only on the binding energy of molecules
   c. both on the binding energy and the kinetic energy of molecules
   d. neither on the binding energy nor on the kinetic energy of molecules

5) When a perfect gas absorbs heat and receives work from the outside, its internal energy ...
   a. increases
   b. decreases
   c. remains constant
   d. increases or decreases, depending on the type of process

6) A heat engine performs a thermodynamic cycle. Its internal energy:
   a. increases
   b. decreases
   c. remains constant
   d. increases or decreases, depending on the type of process
7) During an isochoric transformation, a gas releases heat. Its internal energy:
   a. decreases  
   b. increases  
   c. remains constant  
   d. could increase

8) During an isothermal transformation, a perfect gas absorbs 100 J of heat. Simultaneously, the gas:
   a. has a reduction of its volume  
   b. expands  
   c. keeps its volume constant  
   d. behaves in a way that cannot be predicted univocally

9) A perfect gas makes an isobaric transformation at the pressure of $2 \cdot 10^5$ Pa, increasing its volume of 1 m$^3$, accounting for $10^5$ J of heat. Its internal energy:
   a. decreases by $10^5$ J  
   b. increase by $10^5$ J  
   c. remains constant  
   d. increases by $3 \cdot 10^5$ J

10) A Carnot engine works absorbing heat from a source at the temperature of 500K and giving heat to a cooler at the temperature of 290K. The efficiency of the heat engine is:
   a. 58%  
   b. 100%  
   c. 20%  
   d. 42%
### Strategies After Matching

Match the words on the left with the correct definition on the right:

<table>
<thead>
<tr>
<th>1) Thermodynamics</th>
<th>a) The sum of kinetic energy and potential binding energy of molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>2) Heat engine</td>
<td>a) A form of energy in transit</td>
</tr>
<tr>
<td>3) Heat</td>
<td>b) A series of transformations that always return to the same initial conditions</td>
</tr>
<tr>
<td>4) 4,186 joules</td>
<td>c) Studies the transformation of heat into mechanical energy</td>
</tr>
<tr>
<td>5) Internal energy</td>
<td>d) Device that transforms heat into work</td>
</tr>
<tr>
<td>6) Quasi-static transformation</td>
<td>e) Ratio of useful work and absorbed heat</td>
</tr>
<tr>
<td>7) First Law of Thermodynamics</td>
<td>f) Mechanical equivalent of heat</td>
</tr>
<tr>
<td>8) Thermodynamic cycle</td>
<td>g) A succession of equilibrium states</td>
</tr>
<tr>
<td>9) Performance of heat engine</td>
<td>h) An expression of the changes of the internal energy in a thermodynamic system</td>
</tr>
<tr>
<td>10) The ideal engine</td>
<td>i) Without any heat dissipation, reversible, operating on a perfect gas</td>
</tr>
</tbody>
</table>
State if the sentences are true or false.

1) Thermodynamics was born in the Middle Ages.
2) Joule and calorie are two units of energy.
3) A thermodynamic system exchanges heat and work with the external environment.
4) The internal energy of a system is the sum of the kinetic energy of molecules and the different types of potential energy associated with the molecular bonds.
5) The heat absorbed by a thermodynamic system is considered negative.
6) In an isochoric transformation, the change of internal energy depends only on the exchange of heat.
7) In an adiabatic transformation, the change of internal energy does not depend on heat exchanges.
8) A heat engine transforms work into heat.
9) If a heat engine makes a thermodynamic cycle, there will be no change of internal energy.
10) The efficiency of a heat engine can be 1.
Complete the text.

Thermodynamics is a science that aims to identify ways and limits of converting ... [1] into work. The flow of heat is produced not only by differences in ... [2], but also by the work of ... [3] forces on moving objects. ... [4] proved that there is a constant relationship between the work in Joules and the heat expressed in ... [5] In particular, he calculated that 1 cal = ... [6] Joule. A thermodynamic system is any device that exchanges heat and work with the ... [7]. The first law of thermodynamics is a special formulation of the energy ... [8] principle. Internal ... [9] quantifies the energy level of a thermodynamic system. It is the sum of the ... [10] energy, associated with the motion of molecules and the different types of ... [11] energy, associated with the link between the particles. Internal energy, U, is a function of ... [12] and its variations depend on the initial state and on the ... [13], but do not depend on the type of transformation. Assuming that both the heat ... [14] by a thermodynamic system from the system’s environment during a transformation, and the work ... [15] are positive, the ... [16] Law of Thermodynamics can be expressed mathematically by the equation ... [17]. Thus, the variation of ... [18] energy, in a thermodynamic system, is equal to the algebraic difference between ... [19] exchanged and ... [20] exchanged.
the first law of thermodynamics

10

Strategies After
Flow Chart

Complete the flow chart.
You can use the terms listed below:

\[
\begin{align*}
\text{L}_f & - \quad \Delta U \quad + \quad Q_a \quad - \quad L_s \quad = \quad Q_c \\
\text{start} & - \quad + \quad - \quad = \quad \text{end}
\end{align*}
\]
Strategies After

Think and Discuss

The following activity can be performed in a written or oral form. The teacher will choose the modality, depending on the ability (writing or speaking) that needs to be developed.

The contexts in which the task will be presented to the students are:

A) the student is writing an article about the performance of some real thermal machines.

B) the student is preparing for an interview on a local TV about the performance of some real thermal machines.

The student should:

1) Choose one of the following topics:
   - Describe the reasons that underlie the development of thermodynamics.
   - Try to relate the First Law of Thermodynamics to the more general principle of energy conservation, also referring to what you have studied in previous years.
   - Write a short article on the development of heat engines.

2) Prepare the article or the debate, outlining the main points of the argument, on the basis of what has been studied.

3) If the written activity is the modality chosen by the teacher, the student should provide a written article, indicating the target of readers to whom the article is addressed and the type of magazine / newspaper / school magazine where the article would be published.

4) If the oral activity is the modality chosen by the teacher, the student should present his point of view on the topics to the whole class and a debate could start at the end of his presentation.
In the early nineteenth century, thermodynamics was born, a new science aimed at identifying ways and limits of converting heat into mechanical energy. The flow of heat is produced not only by differences in temperature, but also by the work of frictional forces on moving objects. Joule calculated the constant relationship between work and heat, by establishing that a work of 4.186 Joule may produce a quantity of heat equal to 1 calorie.

A thermodynamic system is a device that exchanges heat and work with the external environment. The size, which quantifies the energy level of a thermodynamic system is the internal energy, U, which is the sum of the kinetic energy associated with the motion of molecules, and the different types of potential energy associated with the link between the particles that compose it. The First Law of Thermodynamics focuses on the total exchanges of mechanical work and heat between the system and the external environment. Considering the positive heat absorbed by the system and the work done by the environment on the system, the negative heat lost from the system environment and the work done by the system environment, the principle can be formulated as \( \Delta U = Q - L \), where \( Q \) is the algebraic sum of heat absorbed and heat transferred, \( L \) is the algebraic sum of the work received and the work done.

To understand real thermodynamic processes, which are always irreversible, we use a model of heat engine consisting of a cylinder with a sliding piston containing a perfect gas.

A thermodynamic transformation is quasi-static if it takes place so slowly as to allow the gas to pass through individual equilibrium positions. These transformations are ideal and reversible, and can be described mathematically and used to approximate real transformations. The ideal transformer can be a perfect gas at constant pressure (isobaric), constant volume (isochoric), at constant temperature (isothermal), or without heat exchange (adiabatic).

In an isochoric model, the gas cannot do work, so the variation of internal energy is equal to the heat exchanged: \( \Delta U = Q \).

In an isothermal model, the gas does not change its internal energy, which depends only on the temperature, so that \( \Delta U = 0 \) and \( Q = L \).
In an adiabatic model, no gas exchanges heat with the outside world, so it satisfies the equation: $\Delta U = L$.

A heat engine is a device that performs labor $L$, at the expense of heat supplied from a hot spring, $Q_a$, part of which ($Q_c$) must be transferred to a cooling system, or cold source, so that the machine can return to the initial cycle and repeat it, having restored the initial values of their state quantities. Thus, a heat engine can operate only by following a series of transformations, which bring it back to the starting conditions, to begin again. In each cycle, we have $\Delta U = Q - L = 0$, therefore $L = Q = Q_a - Q_c$.

The $\mu$ performance of a heat engine is the ratio of useful work done and heat absorbed $Q_a$. Thus in a cycle $\Delta U = 0$ and $Q = L$, we have: $\mu = L / Q_a$.

Carnot's theorem shows that the performance of a real machine is always lower than that of an ideal reversible machine, which works at the same temperature, and depends only on the absolute temperature of the heat source and the cooling system, $T_c$ and $T_f$. We show that $\mu = 1 - T_f / T_c$.

1) **Answer the following questions. The questions could be answered in a written or oral form, depending on the teacher’s objectives.**

   a) Describe Joule’s experiment.
   
   b) What is meant by a thermodynamic system?
   
   c) What is meant by the internal energy of a thermodynamic system?
   
   d) Explain the first law of thermodynamics.
   
   e) What is a quasi-static process?
   
   f) What is the wording of the First Law in the case of an isothermal transformation, of an isochoric transformation, of an isobaric transformation, of an adiabatic transformation?
   
   g) What is a heat engine? What is meant by efficiency?
   
   h) What important result was obtained by Carnot?

2) **Write a short abstract of the summary (max 150 words) highlighting the main points of the video.**
the first law of thermodynamics

Web References

http://zonalandeducation.com/mstm/physics/mechanics/forces/newton/newtonLaw1.html

http://www.chem1.com/acad/webtext/energetics/CE02.html

http://www.grc.nasa.gov/WWW/K-12/airplane/thermo1.html

http://www.ftexploring.com/energy/first-law.html


http://www.youtube.com/watch?v=Xb05CaG7TsQû

http://www.youtube.com/watch?v=dFfsOChfTag&feature=related

http://www.physicsweb.org/TIPTOP/

http://www.cite-sciences.fr/

http://www.exploratorium.edu

http://www.psrc-online.org

13

Activities based on Problem Solving

The following activities can be performed at school, if a computer room is available, or at home. Students are invited to use the web references listed above.

1) Individual activity.

Choose to impersonate one of the following characters and write your report.

a) Going into the details of the thermodynamic cycle, do some research on the internal combustion engine both in relation to its history and its working

b) Going into the details of the thermodynamic cycle, do some research on Diesel engine both in relation to its history and its working

Answer to the following questions:

1) During an isothermal transformation, a gas performs 460 J of work. How much energy, expressed in calories, is absorbed?

2) A gas contained in a cylinder expands at a constant temperature, raising the piston and the load, whose total mass is 15.2 Kg. If the heat absorbed during the process is 60 J, how far is the piston raised?

3) In compressing a mass of 2.3 moles of gas, 940 J of work is done. At the same time, 120 calories is yielded to the environment. Calculate the change in internal energy of each mole.

4) If I breathe on my hand with my mouth open, the air leaving my lungs is hot, but it cools down significantly when I tighten my mouth. Why?

5) A boiler provides 630 kJ of heat to a heat engine, which yields 110 kcal to the cooling system. What is the performance of the engine?

6) Two Carnot machines A and B, respectively, work between 90°C and 10 °C, and between 365 K and 283 K. Which one has the better performance?

7) The efficiency of a steam turbine powered by steam at a temperature of 600 K, is 42%, and is 12% lower than that of an ideal machine, operating between the same temperatures. What is the temperature of the cold source?
8) A small ideal heat engine works between the temperatures of 470 K and 300 K. Determine the power it provides, knowing that every minute it absorbs 250 kJ of heat.

2) Small group activity.

a) Try and reproduce, in the lab, Joule’s experience so as to obtain an acceptable measure of the mechanical equivalent of the calorie.

b) In the lab, try to prepare and develop an isocoric or adiabatic transformation calculating the variation of internal energy of the system, measuring – respectively – exchanged heat and exchanged work.

3) Class project.

Elaborate a poster which illustrates the historical timeline developed between XVIII and XIX centuries, before, during and after the birth of Thermodynamics.
Answer Sheets

Keywords
1) Internal energy, Temperature, Pressure, Volume
2) Work, Heat, Internal energy

Conceptual map:
Multiple choice:
1a, 2b, 3d, 4c, 5a, 6c, 7a, 8b, 9a, 10d

Matching:
1D, 2E, 3B, 4G, 5A, 6H, 7L, 8C, 9F, 10I

True/false:
1 false, 2 true, 3 true, 4 true, 5 false, 6 true, 7 true, 8 false, 9 true, 10 false

Cloze:

Flow Chart:

Problem Solving:
1) [110cal], 2) [40cm], 3) [190J], 4) [in the second case the air undergoes a rapid transformation and adiabatic, which is lowering its temperature], 5) [27%], 6) [B], 7) [318K], 8) [1,5kW].