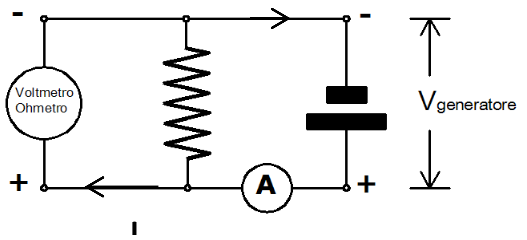
NiTinol Phase Transitions

Equipment

➢ Nitinol one way spring	➢ vertical support bar with horizontal arm
➢ 4 connecting cables	➢ computer
➢ power pack	➢ videocamera
➢ voltmeter	➢ screen or white A4 sheet
➢ temperature probe	➢ ruler or video analysis software
➢ mass hanger + 50 gr masses ➢ (for a total of 300 - 400 g max	➢ timer (optional)

The circuit



Never exceed 3 A in current

and 500 g in mass!

Spring elongation should not exceed 10 cm !

Fig.1 Circuit: electcrical components only

You have on the lab desk a spring which has already been previously stretched as it cooled. The spring is now in detwinned Martensite phase. You will investigate the spring behavior during phase transition:

I) from detwinned Martensite to Austenite, through heating ;

II) from Austenite to detwinned Martensite through mechanical load + cooling .

Procedure

Experimental setup

1. Connect into the circuit spring, voltmeter and power pack (see Fig.1) but don't switch the power pack on yet .
2. Choose an initial mass (e.g.250 gr) and hook it onto the spring.
3. Run a 'full cycle test' without collecting data.

- Switch the power pack on (2,2 A) and observe what happens.
  Notes:
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  ……….
  ……….
- When the spring movements have stopped switch the generator off

- Observe the spring behaviour once again till all variables will be back at their initial condition (you may have to wait for several minutes). As you wait read on through the instructions of this lab sheet and prepare whatever is needed for the videorecording.

Notes and first observations:
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…….
…….

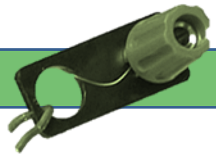
Preparing for videorecording

In the experiment there are quite a few parameters to monitor at the same time and some of the measurements, such as the spring length, should be taken really fast. This is why you will rely on digital images either videos or photos.

- Spring, circuit and measuring tools should be packed tightly together so they can all be whitin the same frame. Check carefully that the digits on the instruments display **are clearly readable** even in the video (see Fig.2 pag.6).
- Put a white sheet to use as a screen behind the springo.
- With a marker or coloured adhesive tape make a sign either on the spring or one of the applied masses. The mark should stand out clearly and be easily spotted by the tracking software.
- Do not change the frame during the recording . Use a tripod or any fixed stand for the videocamera.

Data collection - videorecording

1. Note down the start temperature T_0.
2. Switch on in this order videocamera, voltmetre and power pack.
3. When the spring is totally contracted , leave the power pack on but quickly turn down current to 0,5 A.
4. Let the spring cool down to room temperature.
5. Once the temperature has reached its final value switch the camera off.



Data Analysis

You will work with the digital images to extract the data. First of all save the video on your computer, and in case convert it in a format compatible with the video analysis software [1]. You will obtain the following data: **voltage V, current I, temperature T** (you may read them all from the instruments displays), **electrical Resistance** [2] (indirect measure), time **t** (from the time bar of the video), **displacement S** (through tracking with the software), **spring elongation ΔS (optional).**

Collect data in a table in the electronic sheet .

t (sec)	V(V)	I(A)	R (ohm)	T (°C)	S (mm)	ΔS (mm)

Since you will have quite a number of data concerning different parameters try to devise whether there are any significant relationships among them.

You may answer to the following questions:

1. *Temperature VS time*

The passage of current brings to heating the spring. Once you turn the current down from 2,4 to 0,5 A temperature will reach thermal equilibrium with the environment.

Plot **Temperature VS time.** What's the relationship between the two of them ?

a. You are studying a solid-solid phase transition. Do you notice anything within the graph that may suggest a **phase transition**? Try to find analogies and differences with the well known curves of classical phase transitions (such as liquid/solid).
It may help to repeat the experiment with a lower current (2 A or even lower).
b. During the heating process is there purely **Joule effect?** On which observations do you base your statement?

2. *Displacement VS temperature*

To study how the spring contracts/stretches you may simply study the vertical displacement of any part of the spring or mass hanger taken as a reference point for the tracking program. In fact Δ S = Δ L (with Δ L= spring elongation).

a. With the video analysis software extract data and plot displacement VS temperature.[3]
b. Do the two graphs (warmin/cooling) correspond? Are they the same curve travelled in

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[1] .flv va bene per Tracker.

[2] R si ricava da I e V tramite la legge di Ohm R=V/I. Questo è il motivo per cui anche in fase di raffreddamento viene mantenuta una piccola corrente, sufficientemente bassa da non indurre innalzamento di temperatura e contrazione.

[3] Tracker, free download at *www.cabrillo.edu/~dbrown/**tracker**/* ..

opposite ways or rather two different curves? Why? Try to explain.

c. On the graph identify the different phases and the related transition temperatures (see tangents method [4]).

d. Is there any correspondence between the transition temperatures values found with this method and those exctracted from the video? Start/end of contraction (T^{AS} = Temp. Austenite Start e T^{AF}= Temp. Austenite Finish), start/end of elongation (T^{MS} = Temp. Martensite Start e T^{AF}= temp. Austenite Finish).

Data analysis – Advanced level

3. Trend in Resistance

Resistivity is a fine probe of Nitinol microstructure since through this parameter it is possible to monitor in an indirect way the changes in the crystal lattice. Differently from resistivity Resistance depends also on geometric factors but in this case we may consider them as negligible. Following this assumption resistivity and resistance are directly proportional. You will study R.

- **How is R related to temperature?** Plot the relationship, describe the graph and interpret it highlighting both analogies and differences with the usual behavior of metals .

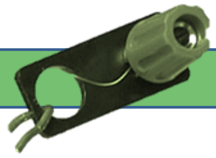
  N.B. Careful: modifications in V will be noticed on the fourth decimal digit! If you read voltage from the pwer pack display only you may not appreciate the difference.Se leggete la tensione dal generatore probabilmente non vi accorgerete delle differenze.
- **Does R depend on temperature <u>only</u>?** It was previously observed that the spring moves in stop and go motion. What's happening to R in those two different moments?
- If you have collected data for different applied masses you will be able to appreciate the effect of the mechanical stress on Resistance. You may consider just the cooling process. Collect the data from the moment when I has reached 0,5 A and settled.

4. Transition temperature VS mechanical applied stress

Change the load applied to the <u>same</u> spring (100, 200, 300,400 gr) and investigate how the curve ΔS(T) varies.

CAREFUL! Each time you change the applied mass run a whole heating/cooling cycle without data collecting: the spring should adapt to the new load and "memorize it" otherwise the plotted graph will not result in a closed loop (e.g go back to the exact initial

[4] Metodo delle tangenti vedi presentazione fatta dal docente.



condition).

- Plot all the data sets in the same graph.
- Find the transition temperatures corresponding to the different loads. Work with the cooling curves: what's happening to T^{MS} e T^{AF} as the load increases ? In 'classical' phase transitions which is the key factor causing transition temperature to change? (just think for instance es. to ice /water phase transition)

5. Displacement of the spring tip or reference point

Investigate in detail the motion of the reference point (displacement, speed, acceleration), possibly repeating each cycle with different applied loads .

- Work with the video analysis software
- Plot the corresponding graphs trying to interpret them according to phase transition

6. Efficiency

Both springs and wires made out of Nitinol are often used as **actuators.** To estimate the efficiency of the Nitinol spring lifting an applied load calculate:

- The input power $\mathbf{P_{in} = VI}$
- The work done **L= mgh** and the output power $\mathbf{P_{out} = L/t}$
- The transformation efficiency $\mathbf{P_{out} / P_{in}}$

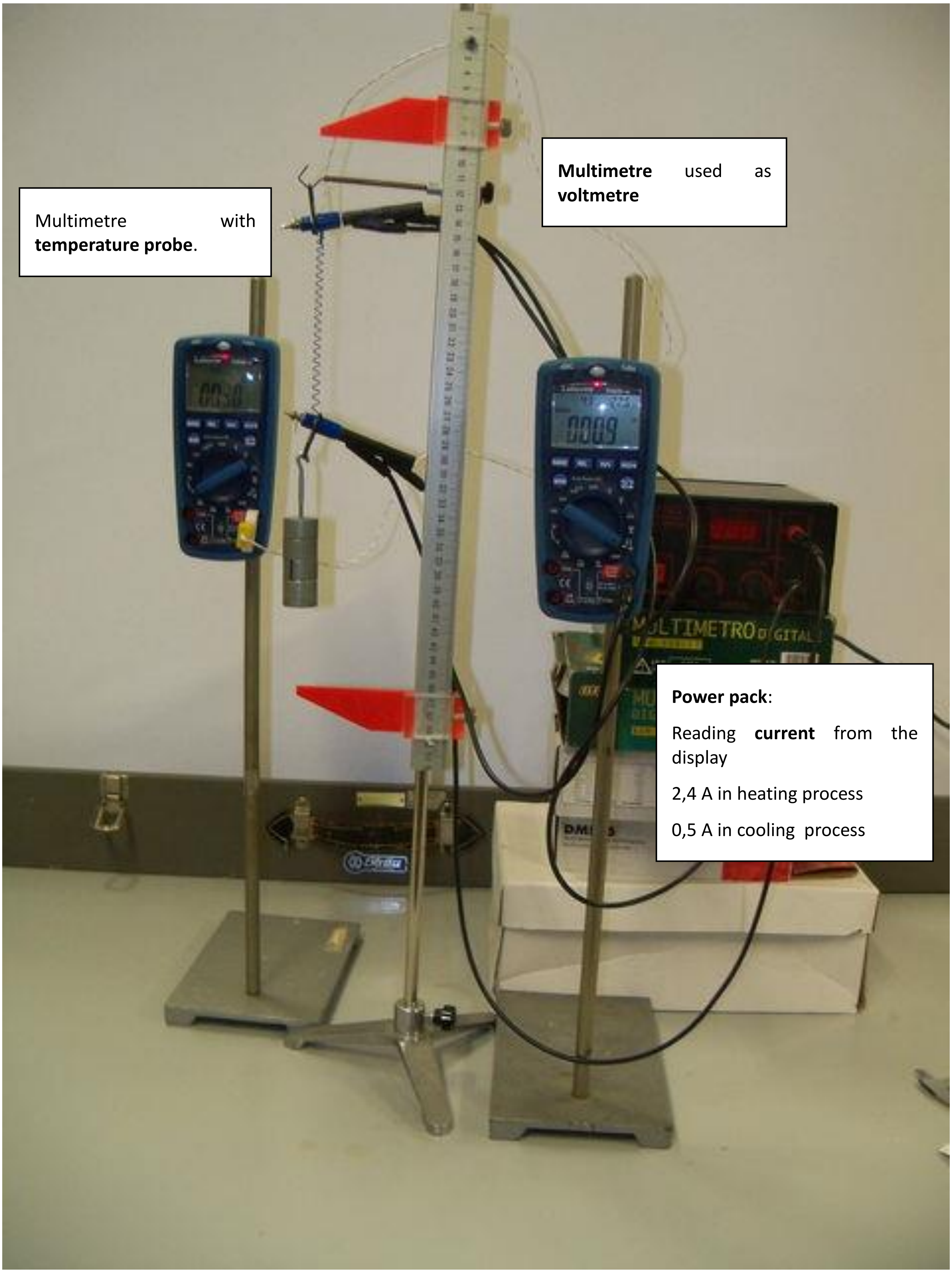
As you modify the current you may also vary the contraction speed of the spring . Which is the relationship between *I* and *v*? What happens to efficiency as you vary *I* ? Be careful not to exceed 3 A!

Science communication -

For its unusual and often spectacular behavior Nitinol is particularly suitable for demonstrations. Discuss how you may modify the proposed path to engage younger students through wow effect activities but with the specific aim of transmitting some kind of scientific message (15 min max)

Which message would you like to pass on? Which expedients and tricks would you use to catch attention, involve and encourage questions?

Fig.2


Multimetre used as **voltmetre**
Multimetre with **temperature probe**.
Power pack:
Reading **current** from the display
2,4 A in heating process
0,5 A in cooling process