

# Didactic resources for teaching Physics online

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**Abstract**—The Interactive Physics Course on the Internet is a project that began in 1998 as an attempt to make the computer a tool for teaching Physics, both inside and outside the classroom.

Last year, the Course began to be completely redesigned. The new XHTML pages, replacing the old HTML pages, are conceived to create a clear separation between content and layout. Each web page is divided in areas, defined by the *div* tag, each area being placed on the page, and being defined (size, internal structure, background...) on an external CSS style sheet.

Using MathML to display mathematical expressions instead of image files has several advantages:

- Better rendering quality and print resolution.
- Better fit and alignment with the rest of the page.

The web pages contain 643 Java applets which are simulations, computer experiments and animations, and also 27 Flash video files of laboratory experiments and lecture demonstrations, because visualization of phenomena is an important part of learning physics.

The Interactive Physics Course on the Internet was not intended to be read from the first to the last page but rather to be used as a reference for a particular problem or to provide some insight into a particular aspect of physics.

**Keywords**—Physics, Interactivity, Multimedia, Applets, Flash video, CSS, MathML.

## I. INTRODUCTION

The Interactive Physics Course on the Internet [1] is a project that intends to improve the quality of the education in Physics, making an effective use of the New Information Technologies.

The web pages contain 643 Java applets that are simulations, computer experiments, interactive problems, etc. The applets allow the observation of the system behaviour and, with the text and diagrams around, facilitate the step-by-step comprehension of the involved physics concepts. They are especially powerful for a better understanding of concepts difficult to grasp, virtual labs and to learn strategies for problem solving.

A physical process can be described using some different representations: text, diagrams, formulae, and applets. Showing animations of a dynamical system and tying it to a coordinated graph, diagram or plot can help the students develop skills in using different representations.

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By setting up a simulation in which students can vary parameters and see the effect of these variations, the students' view of an equation's role is powerfully enriched. In general, the interactive engagement helps the student play a much more active role in his/her learning process.

To reach the mentioned purposes, the web pages have been designed with this structure:

- Introduction of the topic.
- Statements of the physical principles.
- Description of the activities to carry out.
- Finally, we suggest some examples with the purpose of guiding the students to solve the different situations.

The Interactive Physics Course is based on hundreds of articles, from American Journal of Physics, European Journal of Physics, Physics Teacher, Physics Education and Revista Española de Física, that makes it unique and quite different from usual textbooks [2]. We have selected those that:

- Illustrate physical laws and fundamental principles.
- Be easily visualized.

Every physics student learns the analytic solutions of a number of simple problems. More complicated problems are analyzed in terms of general principles like conservation of energy, or in restricted cases like small-oscillations limit. However, many interesting problems are too difficult to solve completely. Such problems can be solved numerically.

We have selected many interesting problems that cannot be solved analytically. Our approach is learning physics, basic numerical methods and Java language at the same time [3]. For this reason, we have written two additional courses:

### Course on Java language:

- Java as an Object Oriented Programming language.
- Applets: Drawing lines, images and text. User interface design.
- Events and event handling.

### Course on Numerical procedures:

- Linear regression.
- Matrices and Vectors. Linear algebraic equations. Eigenvalues and eigenvectors.
- Root finding. Bracketing and bisection method.
- Integration of functions. Simpson's rule.

- Integration of ordinary differential equations. Runge-Kutta methods.
- Monte Carlo methods

The Interactive Physics Course on the Internet covers almost all topics of an Introductory Physics course: units and measurements, kinematics, dynamics, celestial dynamics, rigid bodies, oscillations, waves, transport phenomena, statistical and thermal physics, electromagnetism, and quantum mechanics

For example, the waves chapter is divided in sections: wave motion, sound waves, superposition and interference. Generally, the web pages progress from simpler topics to the most complex throughout each chapter.

The rainbow is one of the most beautiful and impressive of nature's phenomena. The geometrical discussion of the rainbow usually found in textbook is adapted from Descartes analysis.

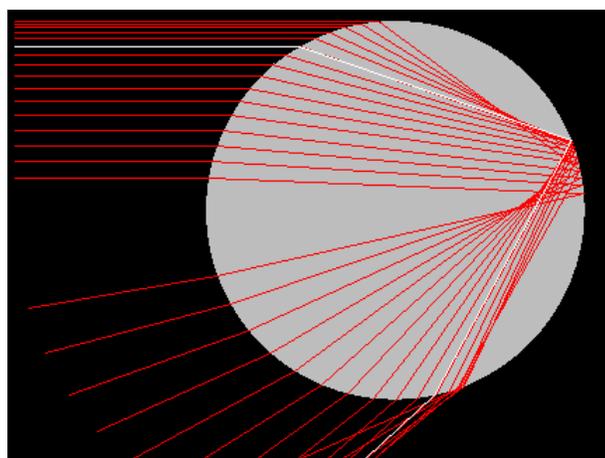


Fig. 1. This image shows the paths of several rays through a raindrop. The cartesian ray (in white) is the ray that experiences the least change of direction.

In our Course we use geometrical optics to explain that rainbows are formed by light being refracted into raindrops, reflected one or more times inside the droplet and refracted back out again, see figure 1. The rays near the Descartes ray emerge in almost the same direction.

Taking into account the variation of the refractive index with wavelength –the dispersion– gives a primary rainbow angle of  $42.4^\circ$  for red and  $40.7^\circ$  for violet light.

The rainbow is strongly polarized. This polarization results from the fact that the angle at which light is reflected inside the drop is close to the Brewster angle, at which the reflection coefficient for p-polarized light is zero.

Rainbows produced by raindrops about 1 mm in diameter or smaller often show several extra bands of colour inside the primary bow, produced by interference of light waves. This interference is described by the Airy function, see figure 2.

The Airy function is quite complex. To plot this function we have taken the source code in C from Numerical Recipes and we have translated it into Java.

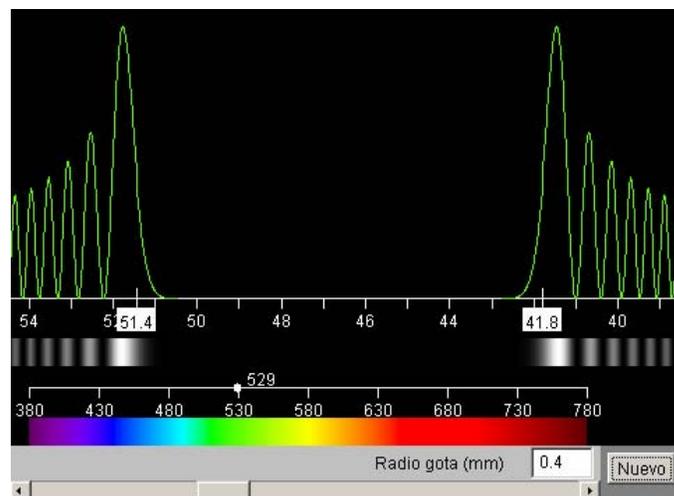


Fig. 2. This image depicts the square of the Airy function for a wavelength (green) and for a given raindrop radius (0.4 mm). The maximum and minimum intensity produces an interference pattern.

Several articles are the sources of information of this web page:

- Whitaker R. J., Physics of the rainbow. *The Physics Teacher*, Vol 12, May 1974, pp. 283-286.
- Hendry A. W., A tripe rainbow?. *The Physics Teacher*, Vol 41, November 2003, pp. 460-463.
- Nussenzevig H. M., Teoría del arco iris. *Investigación y Ciencia*, 9, Junio 1977, pp. 82-94.
- Walker J. D., Multiple rainbows from single drops of water and other liquids, *Am. J. Phys.*, Vol. 44 n° 5, May 1976, pp. 421-433
- Berry M. V. Klein S., Diffraction near fake caustics, *Eur. J. Phys.*, 18, 1997, pp. 303-306.
- Press W. H., Teukolsky S. A., Vetterling W. T., Flannery B. P., *Numerical Recipes in C. The Art of Scientific Computing*, Cambridge University Press, 1992, pp. 250-251

## II. PAGELAYOUT

The first version of this website was created with tables. This method has many disadvantages:

- Multiple imbrication of tables is often necessary, even for simple designs.
- Amount of tags (table, tr, td, colspan, rowspan) becomes huge and weighs the code down, making it difficult to read and to update.

The cascading style sheets separate a document's information from the description of the document's display characteristics. These characteristics reside in separate, reusable files. By using an external style sheet, we have global control over the appearance of every page in our site that is



Presentation markup	Content markup
<code>&lt;math&gt;</code>	<code>&lt;math&gt;</code>
<code>&lt;msup&gt;</code>	<code>&lt;apply&gt;</code>
<code>&lt;mrow&gt;</code>	<code>&lt;power/&gt;</code>
<code>&lt;mo&gt;(&lt;/mo&gt;</code>	<code>&lt;apply&gt;</code>
<code>&lt;mrow&gt;</code>	<code>&lt;plus/&gt;</code>
<code>&lt;mi&gt;x&lt;/mi&gt;</code>	<code>&lt;ci&gt;x&lt;/ci&gt;</code>
<code>&lt;mo&gt;+&lt;/mo&gt;</code>	<code>&lt;cn&gt;2&lt;/cn&gt;</code>
<code>&lt;mn&gt;2&lt;/mn&gt;</code>	<code>&lt;/apply&gt;</code>
<code>&lt;/mrow&gt;</code>	<code>&lt;cn&gt;3&lt;/cn&gt;</code>
<code>&lt;mo&gt;)&lt;/mo&gt;</code>	<code>&lt;/apply&gt;</code>
<code>&lt;/mrow&gt;</code>	<code>&lt;/math&gt;</code>
<code>&lt;mn&gt;3&lt;/mn&gt;</code>	
<code>&lt;/msup&gt;</code>	
<code>&lt;/math&gt;</code>	

MathML content markup has tags with clear semantics for representing basic operators and functions. Algorithms could be described in a programming language-neutral way, then that code for different imperative languages (C, C++ or Java) could be generated from the same MathML content representation.

Presentation markup is our choice because we have included in our web pages equations that are intended only for viewing.

MathML is a low-level language that requires spelling out every detail of an equation, so writing in it directly would be tedious.

We have used MathType by Design Science because it is a powerful, full-featured version of Equation Editor for MS Word. We copy the mathematical expression from MathType and paste it (the presentation markup) into an application like Dreamweaver editor (code view).

It is currently possible to view MathML equations in the leading web browsers. Mozilla is the first major browser with a native implementation of MathML, see figure 5. Internet Explorer needs the MathPlayer plug-in.

As more tools for authoring, viewing and processing MathML become available, its importance is expected to grow.

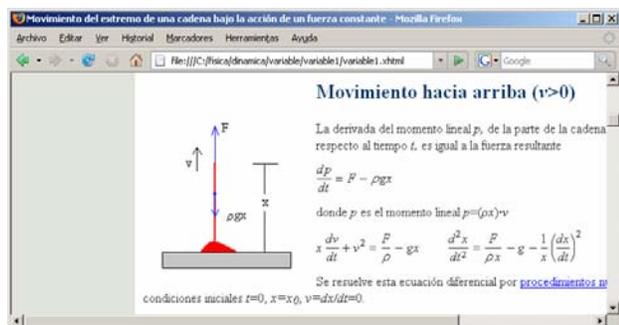


Fig. 5. An XHTML file containing MathML examples displayed in the Mozilla browser

#### IV. JAVA APPLETS

Interactive simulations are new way to convey scientific ideas and engage students in educational activities.

Simulations also provide a unique tool for exploring time dependence in a way that is impossible in print media.

The opportunities span a large space from simple animations with no interactivity to highly interactive simulations with graphics, animations or both.

They are written in a language such ActionScript or Java, so they can be run through a standard browser. This capability provides exceptional flexibility in their educational use. They can be integrated into a lecture or laboratory, used by students in doing homework assignments, or used as an informal resource [4].

- Simulations are powerful tools for helping students visualize electrons, photons, atoms, that they cannot observe directly.
- Simulations directly couple student' actions with the animation. A change of the controls result in an immediate animated response in the visual representations. This interactivity helps students engage with the contents and establish cause-effect relations.
- Many simulations take advantage of the power of computers to quickly do complex calculations without exposing user to the mathematical details. This approach has the potential to transform the way several topics are taught because it allows teachers to focus on the problems that are most important for students to understand rather than on problems that are easiest to calculate.
- Simulations can be greatly enhanced by a good activity which guides students' exploration toward the learning goals and helps place the concepts within a larger context.

We have used the Integrated Development Environment (IDE) JBuilder 2.0 from Borland Inc. to write, compile and deploy the applets created with JDK 1.1 features. The applets are embedded into XHTML documents as JAR files, using the APPLET tag and the ARCHIVE parameter.

#### V. FLASH VIDEO

Unfortunately, most video formats for the web offer no rich media capabilities beyond playback of video in a rectangular window. The video images were often small and ugly, and the overall experience was poor. In the past, several technical challenges kept designers from using video content to its full potential. The advantages of using Flash to present video online include:

- Flash Player has become the most widely installed Internet video client, running on over 96% of all Internet-connected personal computers. Also, Flash Player runs on a wide variety of platforms and operating systems.
- Because Flash treats Flash video as simply another media type, we can layer, script, and control video content just like any other object in a SWF file. Flash video allows designers to create rich experiences that fuse video together with data, graphics, sound, and dynamic interactive control.

To produce a video clip, first, we capture the video with a digital camcorder, we edit the video files with Pinnacle Studio, and we encode the video in the Flash video (FLV) format. Then, we have to decide how to deliver the video; the two primary options are to deliver it as a progressive download (by default) or as a streaming video (using Flash Media Server). A third option is to embed video in the Flash Timeline. However, this is recommended only for very short video clips with no audio track. There are several types of Flash video presentations

#### A. Importing video

It is ideal for situations where we want to put video onto our site quickly and easily, with no interactive elements beyond simple video controls (play, pause, etc), see figure 6.

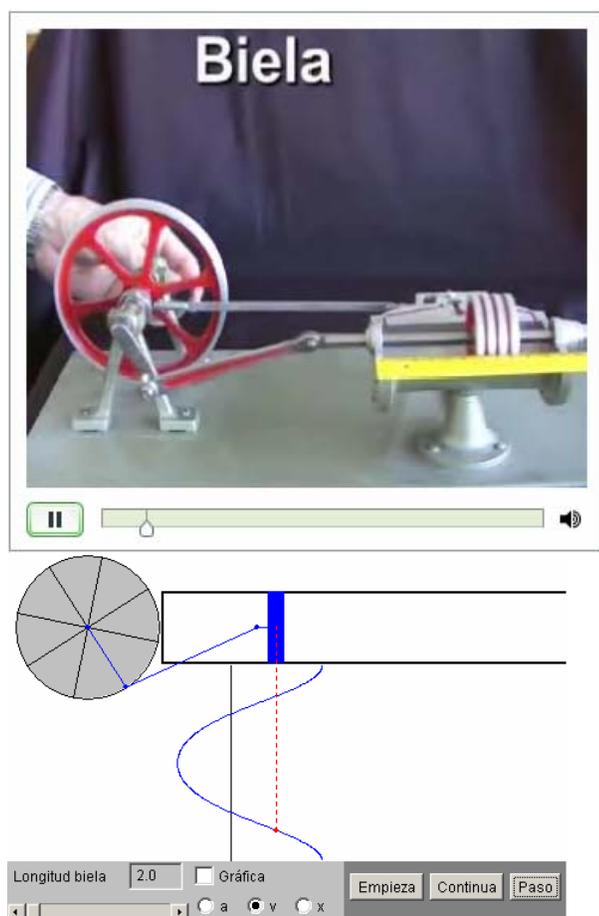


Fig. 6. A video of the piston oscillations. Below an applet that shows that the oscillation is not a Simple Harmonic Motion

#### B. FLVPlayback component

It is a control available in Flash Professional 8 which includes many improvements in workflow, skinning options, and ActionScript API [5].

We can add cue points at various locations in the video using the Flash Video Encoder so that we can synchronize content displays with those points or navigate to those points

by button clicks, see figure 7.

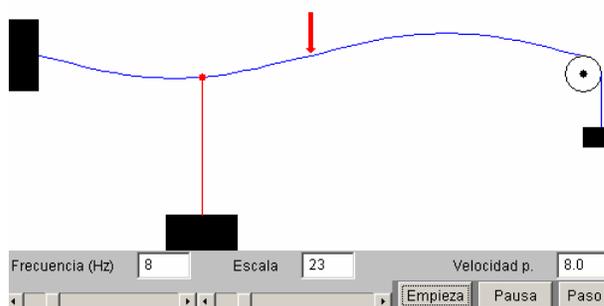


Fig. 7. A string of length  $L$  fixed at both ends has a number of natural patterns of oscillation, called normal modes, each of which has a characteristic frequency. Below a simulation of this experiment.

#### C. Embedded video in the Flash Timeline

One way the video equipment is used in physics is to photograph some sort of motion and then to replay in either slow motion or stop-action. By recording the position of an object in certain frames and knowing the time between frames, the velocity and acceleration of that object can be calculated. Then various other kinematics or dynamics quantities can be estimated.

We have embedded the video in the Flash Timeline in order to play it frame by frame, and use the mouse pointer to display the  $x$  and  $y$  pixel position of a moving object in each frame, see figure 8. The students need to convert their data sets, which contain  $x$  and  $y$  pixel positions of the location of the object with time, to appropriate position units using proportions and a known measurement standard. The Flash program is similar to the free Video Motion Analysis software DataPoint [6].

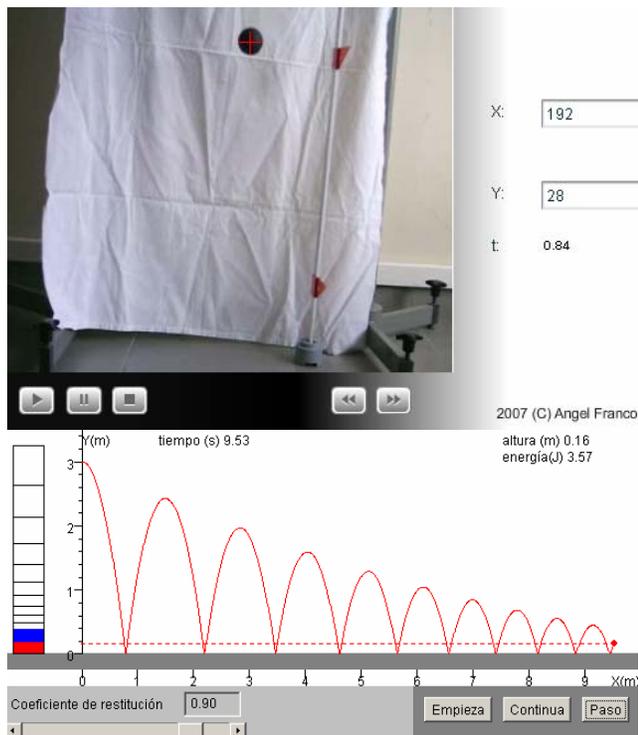


Fig. 8. A ball is dropped from an initial height, we measure the height reached after the nth bounce. From this data we determine the coefficient of restitution for collisions between the bouncing ball and a horizontal surface. Below a simulation of this experiment.

#### D. A presentation with synchronized graphics

It combines audio, video, and animations [7]. While the video plays, the slides change at preset times and the navigation buttons highlight the relevant topic. When the user clicks one of the buttons, the video and slides position themselves to that topic automatically, see figure 9 and 10.

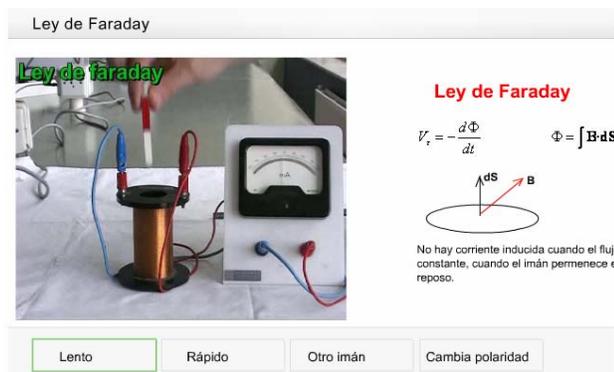


Fig. 9. When a magnet is moved toward or away from a coil connected to a galvanometer an electric current is induced, indicated by the deflection of the galvanometer needle.

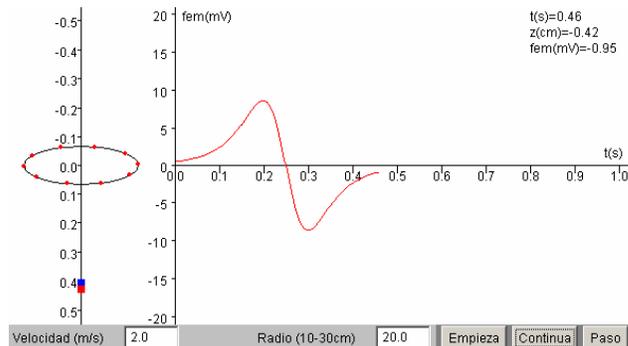


Fig. 10. In this applet, a small strong disk magnet moves with a constant velocity through a coil along the coil axis. The voltage induced in the coil is measured as function of time.

#### E. The Image Viewer media element

It is a Flash application for loading and viewing a series of JPEG images. Users can view images in order with the previous and next buttons or jump to a specific image by entering that image's number. They can also set the images to play in a slide-show format, see figure 11.

The Image Viewer is useful when the lecture demonstration or experiment is a series of images instead of a video.

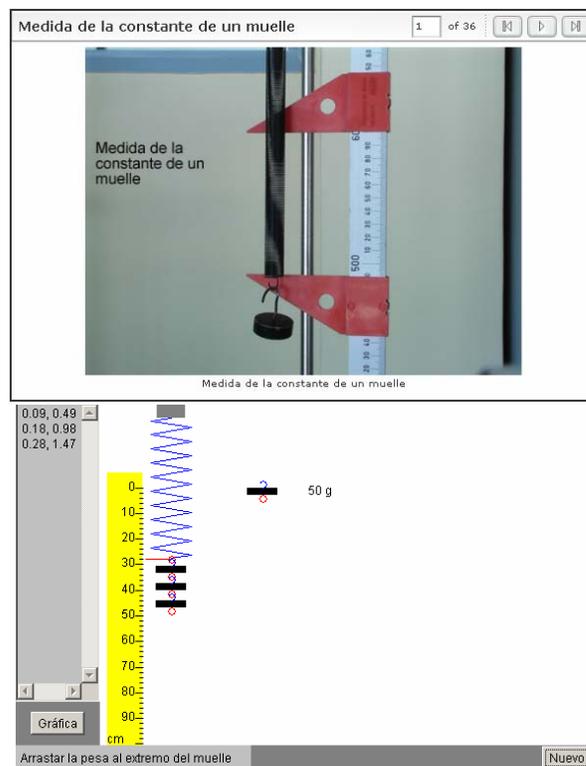


Fig. 11. An Image Viewer of a series of 36 pictures from an experiment on the measuring the spring constant. Below a simulation of this experiment.

## VI. USING THE INTERACTIVE PHYSICS COURSE

When limited to using pictures, words, and gestures in lecture, it can often be difficult to convey to students the dynamic models commonly used in physics.

Simulations are versatile tools for teaching in lecture and

serve as powerful visual aids, complementing traditional classroom demonstrations, they can make the teacher-student communication much easier.

A good simulation will stimulate students to explore the material in a far greater depth that is usually the case from textual or oral presentations.

Applets or videos projected onto a large screen are an excellent starting point for discussion. Some students often spontaneously ask “what happens if you change that?”. They can be encouraged to predict what will happen qualitatively or even quantitatively

For example, a teacher is explaining oscillations: It is better to begin with the simplest type, the simple harmonic oscillator. However, when a real body is set into oscillation, dissipative forces arise. These forces will always result in a damping of the oscillations, a decrease in the amplitude of the oscillation with time. When the oscillator is driven by an externally applied force it is called forced oscillator.

The teacher, instead of drawing static diagrams on the blackboard, can run applets or show videos in order to connect the behaviour of the oscillators (free, damped, driven) to its mathematical description, see figures 12 and 13.

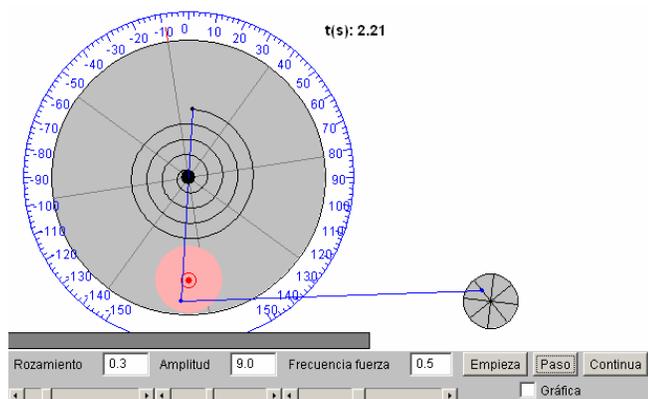


Fig. 12. The torsion pendulum after Pohl can be used to investigate free or forced harmonic rotational oscillations. An electromagnetic eddy current brake damps these oscillations.

The torsion pendulum is excited to forced oscillations by means of a motor-driven eccentric rod.

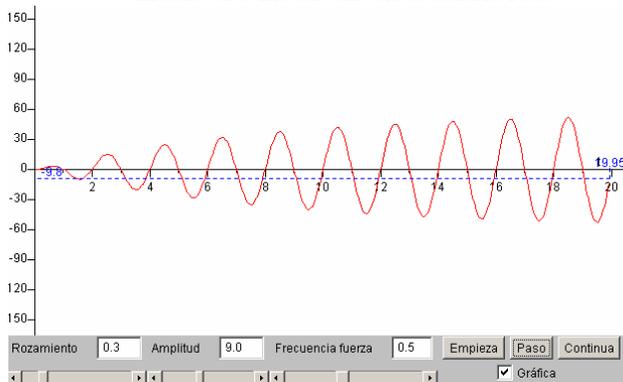


Fig. 13. If an oscillating system is stimulated to swing by an external periodic torque, we observe a transient state followed by a steady state. Its amplitude is a function of frequency, the amplitude of the external periodic torque and the damping.

The Interactive Physics Course on the Internet, allows the students with particular interest to explore the subject more deeply. It creates wider opportunities for students to learn independently and at their own pace either from home or school.

#### A. Difficult concepts

Simulations, in a broad sense, can help the students approach a wider variety of phenomena that they find very difficult to understand from the analytic point of view.

Rolling motion is one of the most interesting motions studied in physics. This interest is derived not only from its close relation to many technical applications, but also to the fact that a correct analysis of this motion requires a good understanding of many different fundamental aspects of great conceptual interest in mechanics. Therefore the rolling motion of a rigid body must receive particular attention in an introductory physics course in science and engineering. However, this topic is often poorly treated in most general physics textbooks. We have developed several web pages and applets which study the frictional force in several contexts: rolling with and without slipping, boxes sliding down a rough ramp, etc.

As a sphere rolls off a grooved track, see figure 14, its angular speed is  $v/r$  which is greater than  $v/R$ , the angular speed it needs to roll without slipping on the floor with a speed  $v$ . Thus the sphere slips when it first hits the floor, until a final speed  $v'$  and a final angular speed  $\omega'$  are reached that satisfy the condition  $\omega' = v'/R$ .

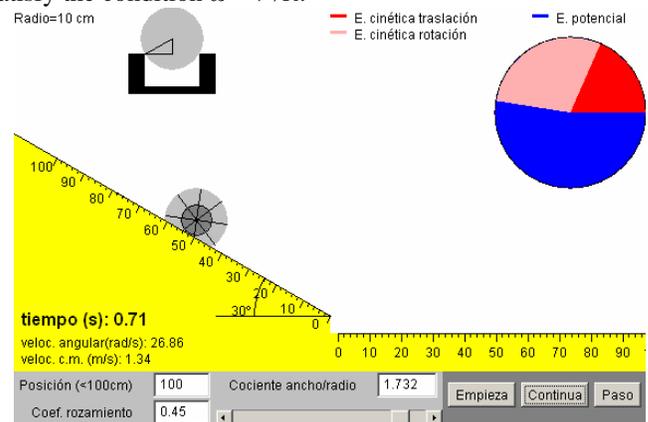


Fig. 14. The motion of a uniform sphere down a grooved track.

#### B. Prelab exercises

Some web pages contain prelab exercises or simulations of laboratory experiments that can be carried out in the school laboratory. Usually, the students work with the simulated experiment before trying the real one. For example, the study of the rectilinear motion, the measurement of a spring constant, and so on. The prelab exercises are an intermediate step between the theory and the real experiment; the students can follow a similar procedure but without the complexities associated to the real experimental setup.

The simulation of laboratory experiments is also a good solution when the experimental setups are inaccessible at the school laboratory, because they are expensive, dangerous or difficult to arrange. For example, some applets simulate the mass spectrometer, particle accelerators, etc. Others recreate relevant experiments from the historical point of view, for instance those that gave place to the discovery of the electron (Thomson and Millikan), the atomic structure (Rutherford), see figure 15, or the existence of discrete energy states (Hertz).

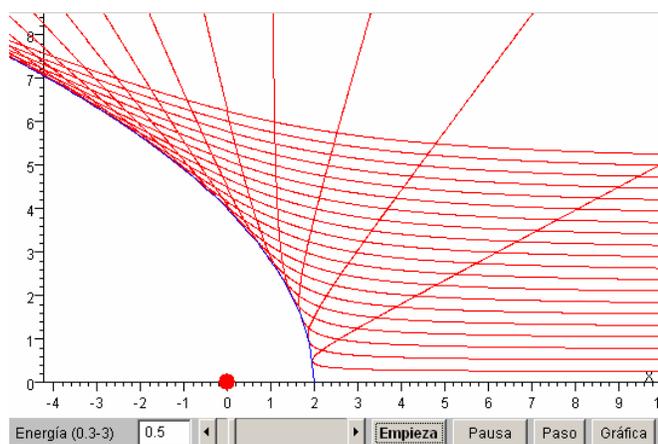


Fig.15. The centre of force, assumed fixed, is at O, and particles approach with impact parameter  $b$ , and initial velocity  $v_0$ , along a line initially parallel to the X axis. We see their hyperbolic trajectories (in red) together with their parabolic envelope (in blue).

### C. Visualization of problems

Some students do not understand the problem statements, and are unable to visualize the physical situation. With an interactive problem the necessary information to solve it is in the applet, not in the text.

The steps to solve an interactive problem are:

- Set the values of the relevant parameters.
- Watch the animation and develop a physics description of the system.
- Divide the problem in steps and apply appropriate principles to each of them.
- Solve the equations numerically.
- Check the answers with the correct solution provided by the interactive program.

This approach may reduce the habit of a high proportion of students to memorize the solutions of the problems that the teacher outlines and solves on the blackboard.

The loop, see figure 16, is a typical problem of an Introductory Physics Course, since it includes the dynamics of the rectilinear motion, the dynamics of the circular motion (in the loop), the concept of work and mechanical energy.

However, many students have difficulty in interpreting not only the formulation of the problem but also the figure, since some believe that the loop is a wheel that comes rolling down along the inclined plane.

An applet has been designed to show a situation similar to the real one. The formulation provided in this way has the advantage that the students can see the motion of the particle before beginning to solve the problem, and they can analyze the problem from the observation of the different stages of the body motion. The formulation is visual and opened up so that the students can build their own physical system changing the spring constant, the friction coefficient of the horizontal and inclined planes, and the loop radius.

The program completes other objectives. The students will be able to realise that the particle has to reach a minimum speed at the lowest point of the circular trajectory to complete the loop. At the upper left of the applet, the student can see how the total energy is distributed, how the energy loses by friction, and perceive the energy transformations along the particle motion.

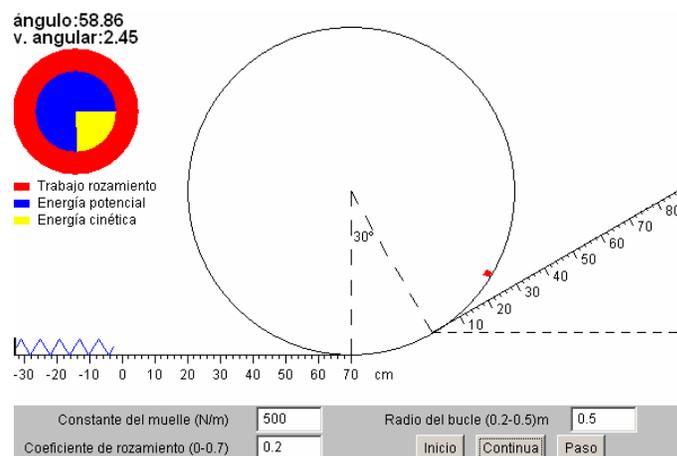


Fig. 16. A block is pushed against a horizontal spring until the spring is compressed a distance  $x$ . When it is released, the block travels along a horizontal surface to a point at the bottom of a vertical circular track, and continues to move up the track.

### D. Numerical procedures

In this situation, students write all of the computational statements to model the physical system and to visualize the abstract quantities.

First, the students must solve the problem: identify all interactions, describe them mathematically, apply fundamental principles, etc.

Then, creating a program gives the students the opportunity to link multiple representations: algebraic equations, the same equations translated into similar program syntax, an animation of an object moving on the screen, a dynamic graph of a quantity such as position or velocity that is generated as object move, etc.

The most significant barrier to the integration of programming is the fact that most students have never before written a program. In an introductory physic course there is little or no time to teach major programming skills. [8]

Some graduate students who are not new to programming have enrolled in a Course of Numerical Procedures in Java.

We have found an interesting problem on the “Up and down vibrations of a hanging chain partly counterbalanced by a suspended body”, [9] in an article from American Journal of Physics. The statement of the problem is as follows: A fine uniform chain is collected in a heap on a horizontal table, and to one end is attached a fine string which passes over a smooth pulley (of negligible mass) vertically above the chain and carries a weight equal to the weight of a length  $a$  of the chain [10]. Figure 16, shows the chain displaced upward a distance  $x$ .

The equations of motion are

- Upward motion

$$\frac{d^2x}{dt^2} = \frac{1}{a+x} \left( g(a-x) - \left( \frac{dx}{dt} \right)^2 \right)$$

- Downward motion

$$\frac{d^2x}{dt^2} = g \frac{a-x}{a+x}$$

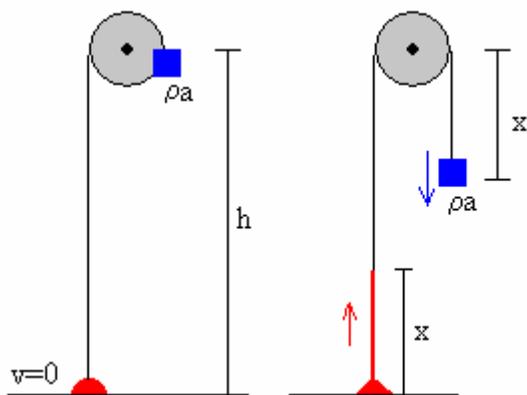


Fig. 17. Initial position of the chain  $t=0$ , and position at time  $t$ .

To describe the complete motion we thus alternately joint solutions of the first differential equations valid for  $dx/dt > 0$  with the solutions of the second differential equation valid for  $dx/dt < 0$ . The merging takes place at the corresponding turning points  $dx/dt = 0$ , at the instants when  $x(t)$  reaches its local maxima or minima, respectively. Supposing the initial conditions  $x=0$ ,  $dx/dt=0$ , see Figure 17, the sequence of turning points for subsequent upward  $x_u/a$  and downward  $x_d/a$  motions of the chain converge to the equilibrium point  $x/a=1$ .

```
public abstract class RungeKutta {
    protected double h;
    public RungeKutta(double h){
        this.h=h;
    }
    public void solve(State e){
        //Runge-Kutta method
    }
    abstract public double f(double
```

```
x, double y, double t);
}

public class SystemDown extends
RungeKutta{
    private double m;
    public SystemDown(double m,
double h){
        super(h);
        this.m=m;
    }
    public double f(double x,
double v, double t){
        double a=9.8*(m-x)/(m+x);
        return a;
    }
}

public class SystemUp extends
RungeKutta{
    private double m;
    public SystemUp(double m,
double h){
        super(h);
        this.m=m;
    }
    public double f(double x,
double v, double t){
        double a=(9.8*(m-x)-
v*v)/(m+x);
        return a;
    }
}

public class MyCanvas extends
Canvas{
    private RungeKutta system;
    private int type;
    private State state;
    private double m=0.3; //block mass
    //...other members
    public void setNew(double m){
        this.m=m;
        state=new State(0.0, 0.0,
0.0);
        system=new SystemUp(m, 0.01);
        type=0;
    }
    public move (){
        switch(type){
            case 0:
                system.solve(state);
                if(state.v<0){
                    system=new SystemDown(m, 0.01);
                    type=1;
                }
                break;
            case 1:
                system.solve(state);
                if(state.v>0){
                    system=new SystemUp(m, 0.01);
```

```

type=0;
    }
    break;
default:
    break;
}
}
//...
}

```

Our numerical approach is to write the code of the Runge-Kutta method in a function *solve()* of an abstract base class *RungeKutta* that calls one function *f* defined in the base class and implemented in two derived classes: *SystemUp* and *SystemDown*. The variable *system* of the type *RungeKutta* (abstract base class), could refer to an object of any of two types.

The statement *system.solve()* is contained in a loop, and gets executed many times. The value of *system* changes depending if the velocity *v* of the end of the chain is  $v > 0$  or  $v < 0$ . The function *f* that is called by the method *solve()* is the appropriate for the type of object to which *system* actually refers. Thus, inheritance and polymorphism helps the programmer to show the complex motion of this variable mass system.

The applet, figure 18, shows the numerical solution of this simple and interesting problem of one-dimensional oscillating motion of a variable mass system. The pie chart gives the energy balance of the system. The damped motion of the chain results from the dissipative processes during landing of the chain on the plane.

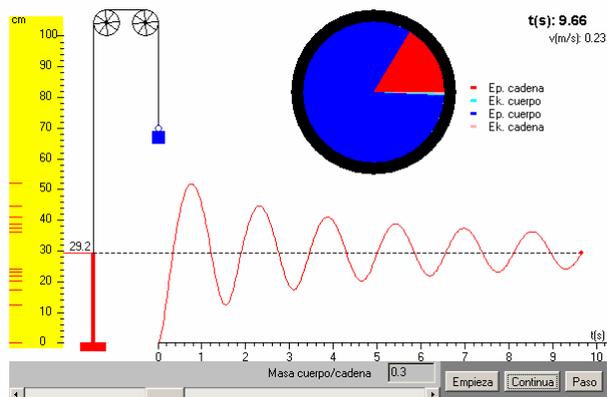


Figure 18. Vibrations of a hanging chain

## VII. CONCLUSION

Articles from journals and magazines are the main sources of information of the Interactive Physics Course on the Internet. We have selected those that illustrate physics laws and fundamental principles. With these foundations, we have built a Course in which we have enhanced the interactivity by means of 643 applets embedded into the XHTML documents. These applets are simulations, computer experiments, interactive problems, computer games, etc. There are also 27

Flash video files of laboratory experiments and lecture demonstrations.

The Interactive Physics Course, the Java and the Numerical Methods courses can be freely downloaded from the Internet. Therefore, students and their teachers have at their disposal a collection of interesting problems of all topics (mechanics, thermodynamics, etc.), with analytical or numerical solution and in some cases, both.

We are committed to bring to our thousand of users:

- New and interesting contents based on articles from physics journals.
- New ways to present that information.

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