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# CALCULATION AND VISUALIZATION OF A BODY MOTION IN A GRAVITATIONAL FIELD

**Abstract.** The article presents the program for calculation and visualization of a material particle motion trajectory in a gravitational field of two motionless objects M1 and M2. The system of differential equations of the particle motion is solved using the ode45 procedure of the MATLAB system. At first the m-file under the title «f=finit2(t,x)», is created and then it is connected from a command line. Experiments with change of mass of the second motionless object are made, i.e. at M1=50 for M2=0; 0.2; 1; 2; at M1=49 for M2=0; 1; 2; at M1=47 for M2=0.5; 1.0. The movement of a point in the field of one motionless object happens along an ellipse, and introduction of other motionless object of small mass leads to perturbation of an orbit and the trajectory isn't closed. Initial parameters are introduced as global. By changing initial parameters it is possible to get various models of the particle's motion in the gravitational field. The results of this study can be used on theoretical mechanics classes of the higher school.

**Key words:** gravitational field, trajectory, perturbation, ode45 procedure.

Nowadays all educational institutions of Kazakhstan are provided with computer hardware and software, interactive boards and internet. Almost all teachers have completed language and computer courses of professional development. Hence the educational institutions have all conditions for using computer training programs and models for performing computer laboratory works. In recent years we conduct work on organization computer laboratory works on physics with use of resources of the Fizikon Company [1] and [2], developed at Al-Farabi Kazakh National University by V. V. Kashkarov and his group. Some of worksheet templates for computer laboratory works are introduced in educational process of our university and schools of the Southern Kazakhstan [3-29]. Students of the specialties 5B060400 and 5B011000-physics successfully study the discipline "Computer modeling of physical phenomena" which is the logical continuation of the disciplines "Information technologies in teaching physics" and "Use of electronic textbooks in teaching physics". The aim of this discipline is to study and learn the program language of the MATLAB [30] system, acquaintance with its huge opportunities for the modeling and visualization of physical processes. The MATLAB system is widely applied for calculating and visualization of problems of applied mechanics which are studied by students of specialties 5B070600-Geology and exploration of mineral deposits, 5B071200-Mechanical engineering, 5B072900-Construction, 5B072400-Technological machines and the equipment, 5B071300-Transport, transport equipment and technologies, 5B070800-Oil and gas business, 5B090100-Organization of transportations, movement and operation of transport.

This article is devoted to calculation and visualization of a body motion in a gravitational field using MATLAB software package.

Laboratory work "Calculation and visualization of a body motion in a gravitational field of two motionless objects".

Aim of the work: to work out the program for calculation and visualization of a body motion in a gravitational field of two motionless objects.

Formulation of the problem: A particle of mass *m* moves in a gravitational field of two motionless objects with masses M1 and M2 (figure 1).

The motion of the particle with mass *m* is described by the following equation

$$m\ddot{\vec{R}} = -G\frac{mM_1}{\left|\vec{R}-\vec{r}_1\right|^3}\left(\vec{R}-\vec{r}_1\right) - G\frac{mM_2}{\left|\vec{R}-\vec{r}_2\right|^3}\left(\vec{R}-\vec{r}_2\right) \qquad (1)$$

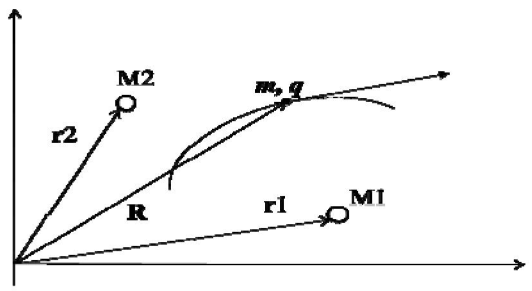


Figure 1 – The diagram of a location of the particle with mass *m* in gravitational field of two motionless objects with masses M1 and M2

The equation (1) is the second-order differential equation. It can be reduced to the first-order equation:

$$\dot{\vec{R}} = \vec{V}$$
$$\dot{\vec{V}} = -G\frac{M_1}{\left|\vec{R}-\vec{r}_1\right|^3}\left(\vec{R}-\vec{r}_1\right) - G\frac{M_2}{\left|\vec{R}-\vec{r}_2\right|^3}\left(\vec{R}-\vec{r}_2\right) \qquad (2)$$

We suppose that motion occurs on the plane and introduce the following denotations:

$$\vec{R} = (x1, x2),\ \vec{r}_1 = (c1x, c1y),\ \vec{r}_2 = (c2x, c2y),\ \vec{V} = (x3, x4) \qquad (3)$$

Using these denotations we rewrite the equation (2) as the followings

$$\dot{x}1 = x3;\ \ \dot{x}2 = x4;$$
$$\dot{x}3 = -G\frac{M1(x1-c1x)}{\left((x1-c1x)^2+(x2-c1y)^2\right)^{3/2}} - \frac{M2(x1-c2x)}{\left((x1-c2x)^2+(x2-c2y)^2\right)^{3/2}}; \qquad (4)$$
$$\dot{x}4 = -G\frac{M1(x2-c1y)}{\left((x1-c1x)^2+(x2-c1y)^2\right)^{3/2}} - \frac{M2(x2-c2y)}{\left((x1-c2x)^2+(x2-c2y)^2\right)^{3/2}};$$

Without impact on the solution of the problem, we take the value of a gravitational constant to be equal to G=1 and M1=50. M2=0 (their values can be changed). Also we suppose that coordinates of motionless objects are c1= (5,0), c2= (0,10). Then the system of the equations can be written as m. file under the title finit2.

Listing of the m. file

```
f=finit2(t,x)
global M1 M2 c1x c1y c2x c2y
f=[x(3);x(4);...
-M1*(x(1)-c1x)/(sqrt((x(1)-c1x)^2+(x(2)-c1y)^2))^3-...
M2*(x(1)-c2x)/(sqrt((x(1)-c2x)^2+(x(2)-c2y)^2))^3;
-M1*(x(2)-c1y)/(sqrt((x(1)-c1x)^2+(x(2)-c1y)^2))^3-...
M2*(x(2)-c2y)/(sqrt((x(1)-c2x)^2+(x(2)-c2y)^2))^3];
end
```

The program of the movement of a particle of mass *m* in the field of one motionless object with mass M1=50. In the command line of MATLAB we write

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000; % input of parameter
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y) % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 2.

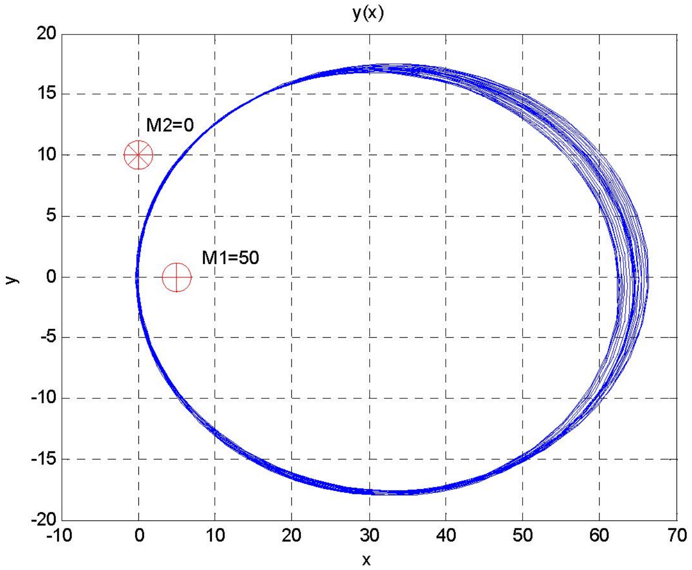


Figure 2 – The trajectory of a particle motion in a gravitational field of one motionless object with mass M1

It is known that the particle in a gravitational field of one motionless object with a certain mass moves along an ellipse or a circle. In the figure 2 the line trajectory is indistinct. This is due to insufficient accuracy of the calculation. By default the accuracy of calculation of the ode45 procedure is 1e-6 which isn't enough for the considered problem. Therefore, in the ode45 procedure the calculation accuracy is taken to be 1e-9.

```
>> global M1 M2 c1x c1y c2x c2y
 >>M1=50; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000;
>> tol=1e-9;
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0],odeset('RelTol',tol));
>>x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>>plot(x,y) % drawing the trajectory of the motion
>> grid on
>> hold on% drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
 >>plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
```

```
>>gtext('M1=50') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 3.

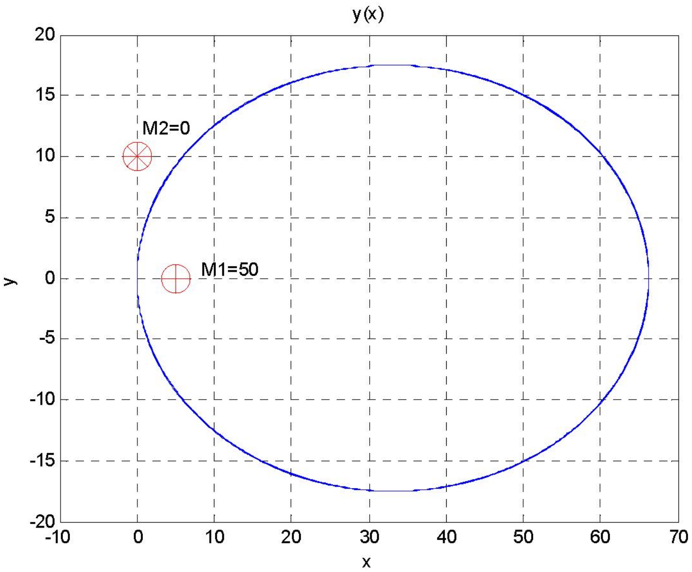


Figure 3 – The trajectory of a particle motion in a gravitational field of one motionless object with mass M1

Now we have got the perfect picture of the trajectory.

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=50 and M2=0.2.

```
>> M1=50; M2=0.2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> gtext('M2=0.2') % input of the notation in the figure
>> gtext('M1=50') % input of the notation in the figure
```

The result is presented in the figure 4.

Figure 4 shows that introduction of the second motionless object with a small mass of M2=0.2 leads to disturbance of an orbit and the orbit isn't closed.

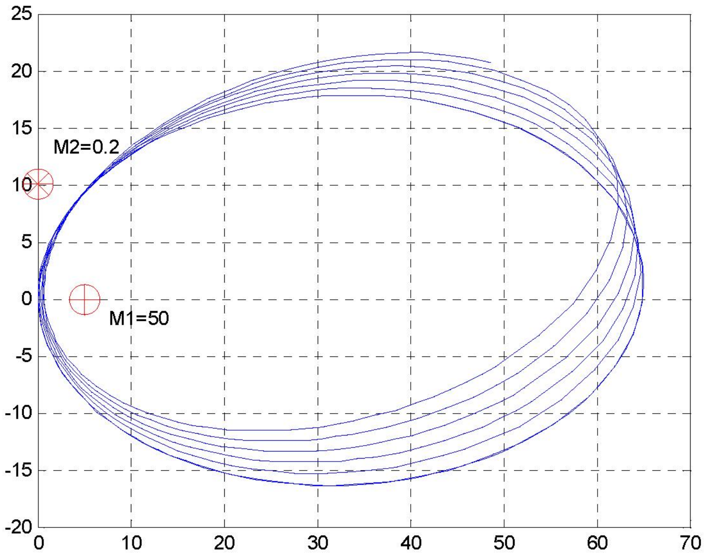


Figure 4 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=50 and M2=0.2

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=50 and M2=1.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M1=1; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure
```

The result is presented in the figure 5.

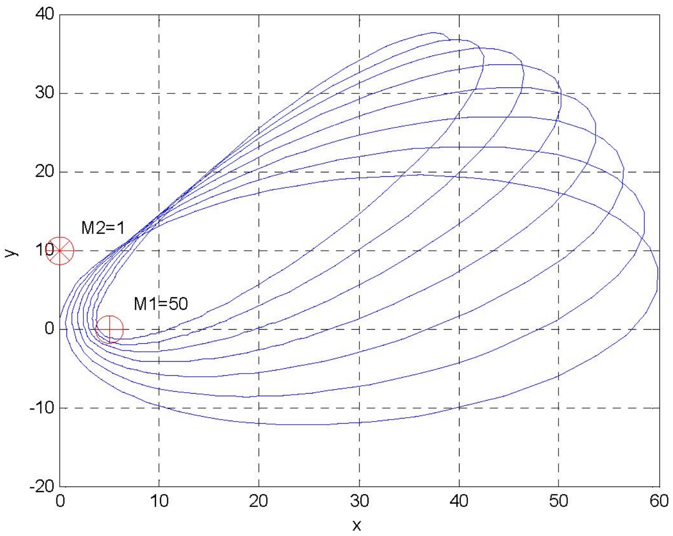


Figure 5 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=50 and M2=1

Figure 5 shows that the increase in mass of the second motionless object leads to a greater disturbance of the orbit.

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=50 and M2=2.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=2') % input of the notation in the figure
```

The result is presented in the figure 6.

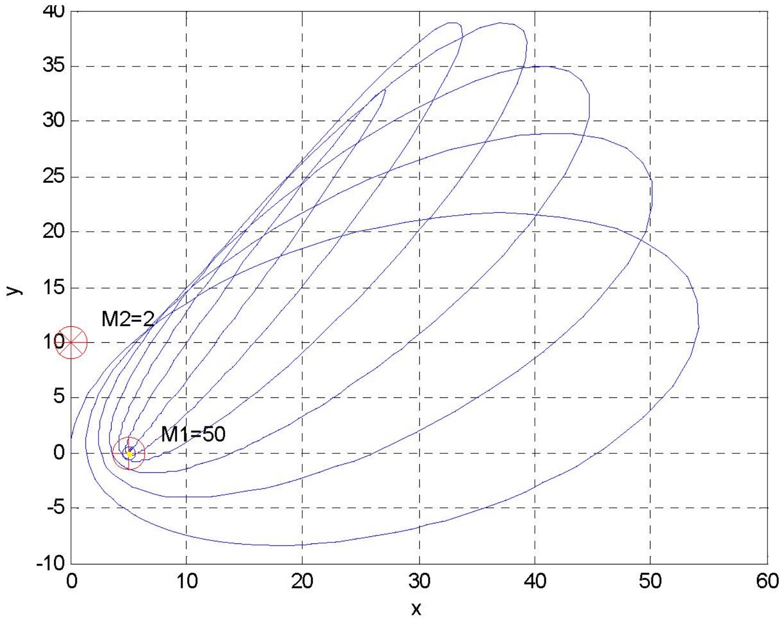


Figure 6 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=50 and M2=2

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=49 and M2=0.

```
>> global M1 M2 c1x c1y c2x c2y
 >> M1=49; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=300; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 7.

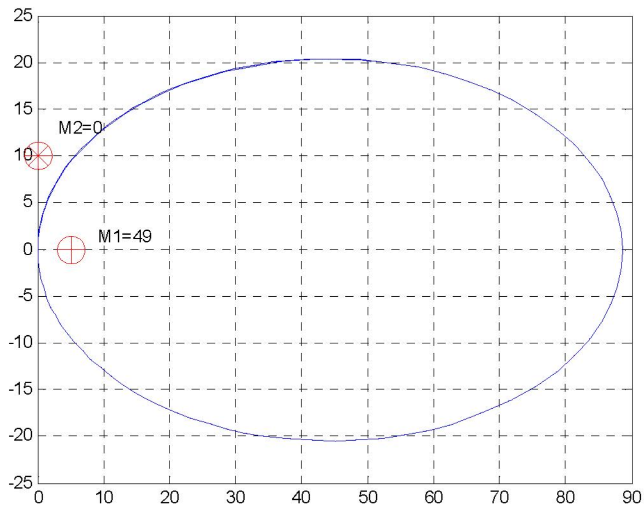


Figure 7 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=49 and M2=0

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=49 and M2=1.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=49; M2=1; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
>> % drawing the location of motionless objects
 >> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure
```

The result is presented in the figure 8.

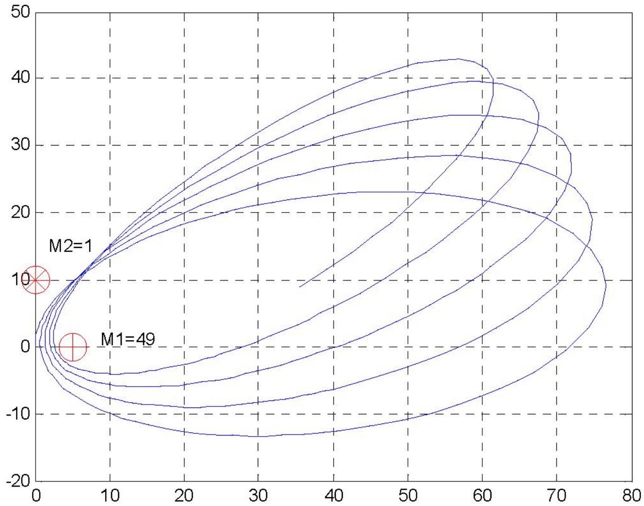


Figure 8 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=49 and M2=1

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=49 and M2=2.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=49; M2=2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=2') % input of the notation in the figure
```

The result is presented in the figure 9.

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=47 and M2=0.5.

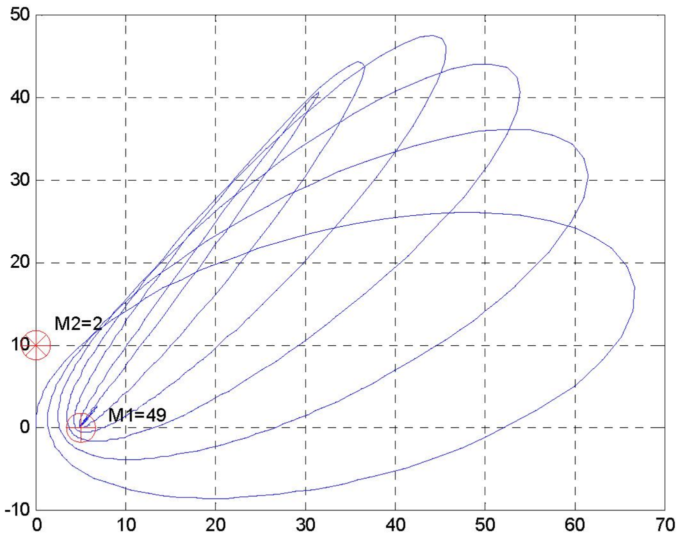


Figure 9 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=49 and M2=2

```
>> global M1 M2 c1x c1y c2x c2y;
>> M1=47; M2=0.5; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=47') % input of the notation in the figure
>> gtext('M2=0.5') % input of the notation in the figure
```

The result is presented in the figure 10.

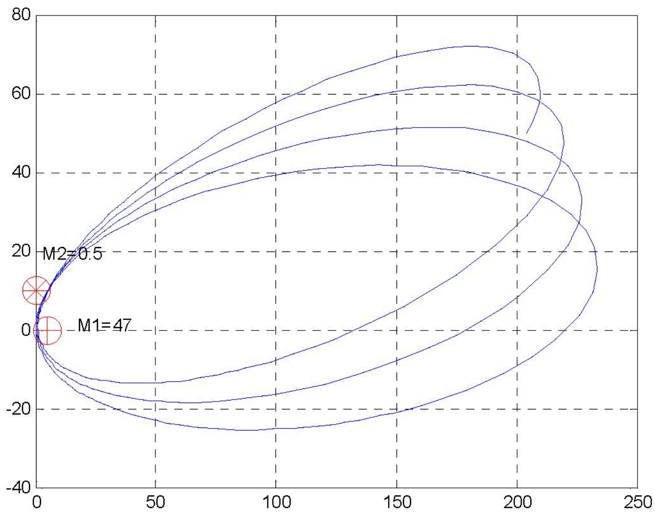


Figure 10 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=47 and M2=0.5

The program of the movement of a particle of mass *m* in the field of two motionless objects with masses M1=47 and M2=1.

```
>> T1=4000; M1=47; M2=1;
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y) % drawing the motion trajectory
>> grid on% drawing the coordinate grid
>> hold on% drawing the next element
% drawing the location of motionless objects
 >> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
 >> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=47') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure
```

The result is presented in the figure 11.

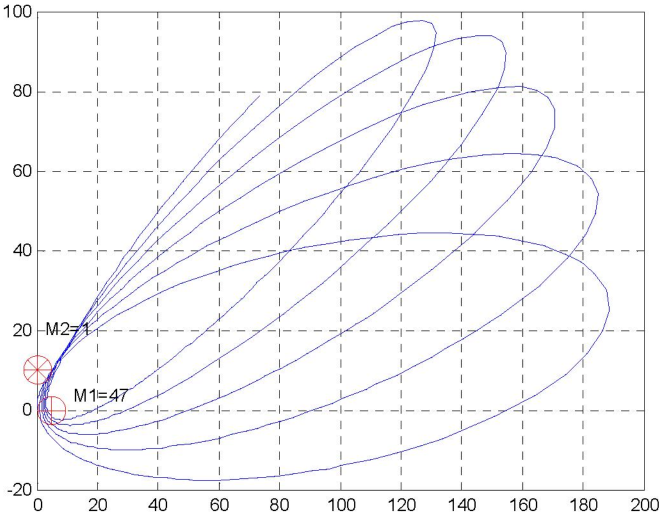


Figure 11 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses M1=47 and M2=1

**Conclusion.** The program allows performing modeling at various initial parameters: for example at M1=50 and M2=0; 0.2; 1; 2; at M1=49 and M2=0; 1; 2; at M1=47 and M2=0.5; 1.0. Students are suggested to simulate independently for other various initial parameters by changing calculation accuracy using the command "odeset ('RelTol', tol)".

The use of the MATLAB language for simulation of the material particle motion in the gravitational field of two motionless objects with different masses helps greatly in study of the gravitational field influence on the particle's motion.

The movement of the particle in the field of one motionless object happens along an ellipse, and introduction of other motionless object of small mass leads to perturbation of an orbit and the trajectory isn't closed.

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## ДЕНЕНІҢ ГРАВИТАЦИЯЛЫҚ ӨРІСТЕ ҚОЗҒАЛЫСЫН ЕСЕПТЕУ МЕН БЕЙНЕЛЕУ

**Аннотация.** Екі тыныштықтағы М1 және М2 объектілердің гравитациялық өрісінде материялық нүктенің траекториясын есептеу мен бейнелеу ұсынылғанПредлагается программа расчета и визуализациии. Қозғалыстың дифференциалдық теңдеулер жүйесі MATLAB жүйесінде ode45 процедурасымен шешіледі. Ол үшін алдын-ала «f=finit2(t,x)» деп аталатын m-файл жазылады және ол MATLAB тың командалық строкасынан қосылады. Тыныштықтағы бірінші объектінің массасын өзгертпей М1=50, тыныштықтағы екінші объектінің массасын М2=0; 0.2; 1; 2 шамаларында өзгертіп эксперименттер жүргізілген;

Сонымен қатар М1=49, М2=0, 1, 2; М1=47, М1=0.5,1.0 шамалар бойынша эксперименттер қайталанған. Тыныштықтағы бір объектінің өрісінде материялық нүктенің қозғалысы эллипс бойында, ал екінші объект қосылғанда нүктенің траекториясы шамалы өзгереді де траектория тұйықталмайды. Бастапқы параметрлер глобалды деп жарияланған. Бастапқы парметрлерін өзгерту арқылы материалдық нүктенің гравитациялық өрістегі қозғалысының әр түрлі моделін алуға болады.

Зерттеу нәтижелері жоғары оқу орындарындағы теориялық механика дәрістерінде қолдануға болады.

**Түйін сөздер:** гравитациялық өріс, траектория, өзгерту, ode45 процедурасы.

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## РАСЧЕТ И ВИЗУАЛИЗАЦИЯ ДВИЖЕНИЯ ТЕЛА В ГРАВИТАЦИОННОМ ПОЛЕ

**Аннотация.** В статье приводится расчет и визуализациия траектории движения материальной точки в гравитационном поле двух неподвижных объектов М1 и М2. Решение системы дифференциальных уравений движения проводится процедурой ode45 системы MATLAB. Сначала создается m-файл под названием «f=finit2(t,x)», который подключается с командной строки. Далее проводится моделирование с изменением массы второго неподвижного объекта при постоянной массе первого объекта: М2=0; 1; 2 при М1=50; М2=0, 1, 2 при М1=49; М1=0.5 и 1.0 при М1=47. Движение точки в поле одного неподвижного объекта происходит по эллипсу, а введение другого неподвижного объекта малой массы приводит к возмущению орбиты и траектория незамкнута. Исходные параметры объявлены как глобальные. Меняя исходные параметры можно получить разные модели движения материальной точки в гравитационном поле.

Результаты исследования могут быть использованы на занятиях по теоретической механике в высших учебных заведениях.

**Ключевые слова:** гравитационное поле, траектория, возмущение, процедура ode45.

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