This set of problems consists of 11 pages in total.

1. The exam consists of 11 pages of problems. Please put your answer sheets together. You will have one number and total number of pages. On the blank answer sheets also indicate the problem number.

2. At the end of the exam please put your answer sheets in order. You may have one page left.

3. Please indicate on all sheets your full name, student number, number of pages, and total number of pages. In such cases you may add the total of a previous part as given in the form text, but you must be able to separate parts of a problem without having solved the problem completely.

4. For anything else you may want to consider for evaluation, please mark your results on the answer sheets.

5. Write as little text as possible in your answers. Express yourself primarily with graphs. Include fractions, numbers and figures. Summarize your results on the answer sheets.

6. Use only the front side of the answer sheets.

I. Use only the pen provided.

Read this first:

9 a.m. – 2 p.m.

Saturday, July 4th, 1998

Theoretical competition

Reykjavík, Iceland

29th International Physics Olympiad
and write the value of the coefficient in the answer sheet.

\[ \text{ins} = l_m \]

Show that we may write

Immediately after the impact, vector \( l_m \) before a given edge force the plane is \( l_m \) while the angular velocity vector follows along edge and that the prism does not lose contact with the plane. The angular velocity of the prism is now displaced from rest and starts an uneven rolling down the plane. Assume that friction is negligible. Let the prism be a right triangle with the horizontal (Figure 1.2). Assume that the surface of the plane makes a small angle \( \theta \) with the horizontal. (Figure 2.1) Consider a more solid, rigid, regular hexagonal prism like a common type of pencil (Figure 1.1)

\[ \varepsilon \left[ \begin{array}{c} 1 \\ \frac{\pi}{3} \end{array} \right] = I \]

Problem text

1.1 Rolling of a hexagonal prism
3

momentum about the edge is conserved during the brief interval of impact. The plane
 ATK the impact the prism starts rotating about a new axis, i.e, the edge which just hit

Solution Method 1

(a) 1.2 Solution

Sheer rolling once started, will continue indefinitely. While your numerical answer on the answer
sheet, the coefficient in terms of and in the answer sheet,

\[ \theta \sin \theta = \sigma' M \]

Given that the limit exists, show that \( \theta' \) may be written as

\( \theta \) such that the prism rolls down the incline. The condition of part (c) is satisfied, the kinetic energy \( M \) will approach

(1.6)

and where the coefficient \( \theta \) is the acceleration of gravity,

\[ \theta = \frac{9.81 \text{ m/s}^2}{9} \]

which may be written in the form

(1.7)

which must exceed a minimum value \( \theta' \) must exceed a minimum value \( \theta' \) which may be written in the form

(1.4)

Show that we may write

(1.5)

and \( \theta' \) of the impact energy of the prism just before and after impact is similarly \( \theta' \)

Figure 1.2: A hexagonal prism lying on an inclined plane.
Equation (1.1) $\frac{1}{2} m v^2 \frac{\vec{r}}{I} = \frac{1}{2} m v^2 \left( \frac{\vec{r}}{I} + \frac{\vec{r}}{F} \right) = \frac{1}{2} m v^2 \frac{\vec{r}}{I} + \frac{1}{2} m I = \frac{1}{2} I$

Equation (1.2) $\vec{v} \times \vec{r} = \vec{v}$

Hence we get for the quantities: before impact

\[ \text{force} = \text{momentum} \]

\[ \text{momentum} = \text{momentum} \]

**Figure 1.3: The lower momentum of the prism as whole before and after impact.**

From the plane, see Figure 1.3. is directed 30° downward relative to the plane, but will after impact point 30° upward is easy to follow where we know the axis of rotation of a given line. Just before impact $\vec{p}$ mass where the subscript $\vec{r}$ refers to the center of mass and this direction is the vector of the center of momentum of the prism as whole has the same direction as the vector of the lower momentum.
\[ I_m \cdot \frac{\partial N}{\partial L} + I_m I = \left( I_m + \frac{\partial N}{\partial I} \right) I = I \]

Of course, the same result as before.

Equations (1.1), (1.2), and (1.3) can now be solved for the ratio of the right-hand side of the equation above, since the right-hand side is the change in angular momentum about the center of mass.

\[(f_m - \frac{\partial N}{\partial I}) I = \frac{1}{\partial N} \frac{\partial}{\partial I} \frac{\partial N}{\partial I} \]

We finally have:

\[(f_m + \frac{\partial N}{\partial I}) I = \frac{\partial}{\partial d} \frac{\partial N}{\partial I} I = d \]

We can set up three equations with three unknowns with the corresponding change in perpendicular angular momentum. Thus:

The general is the change in the perpendicular component of the angular momentum of the two rods, and the rate of change of the perpendicular component of the plane (positive or negative) appears on the left.

We may note that \( s \) is independent of \( a, i, \) and \( \theta \).

\[ 2L/2 = s \]

We thus get:

\[ \frac{\partial N}{\partial I} = \frac{2L/2}{2L/2} = f_m \]

Now, when we observe a relation between the angular velocities as follows:

we scale the conservation of angular momentum, i.e., \( f_m I = f_m I = I \)
In the general case, we have shown that we have the relation

\[ \frac{\theta \sin \frac{\pi}{2} + \theta \cos \frac{\pi}{2}}{2} = \left( \theta - \cos(3\theta) \right) - \frac{1}{4} \]

(12.2)

Thus

\[ \left( \theta - \cos(3\theta) - 1 \right) \frac{d}{dt} = 0 = \frac{d}{dt} \]

and we get the condition

\[ \left( \theta - \cos(3\theta) - 1 \right) \frac{d}{dt} = 0 = \frac{d}{dt} \]

(12.1)

\[ \left( \theta - \cos(3\theta) - 1 \right) \frac{d}{dt} = 0 = \frac{d}{dt} \]

where \( a = 0 \) is the top angle of the triangle meeting at the center of the polyhedron. The energy for this triangle is the kinetic energy of the center of mass is the kinetic energy of the center of mass.

\[ \theta - \frac{C}{V} = x \]

(11.1.1)

\[ \theta - \frac{C}{V} = x \]

(11.1.1)

\[ \theta - \frac{C}{V} = x \]

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(11.1.1)

\[ \theta - \frac{C}{V} = x \]

(11.1.1)
\[
\begin{align*}
(53.1) & \quad (u^t Y_{1^d - 1} - \nabla)_{1^d - 1} = \\
(54.1) & \quad \nabla_{1^d - 1} + u^t Y_{1^d - 1}(I - d) = u^t Y_{1^d - 1} + u^t Y = u^t Y
\end{align*}
\]

In the limit of \(u \to \infty\) we get

\[
\begin{align*}
(53.1) & \quad \frac{d - 1}{\nabla} = \sigma^t Y \leftarrow u^t Y \\
(54.1) & \quad \nabla \frac{d - 1}{\nabla} + u^t Y_{1^d - 1} = \\
(55.1) & \quad \nabla (2^d - 1^d + \cdots + 1^d + 1) + u^t Y_{1^d - 1} = u^t Y \\
(56.1) & \quad \nabla (d + 1) + u^t Y_{1^d - 1} = \nabla + \sigma^t Y \quad = \sigma^t Y \\
(57.1) & \quad \nabla + \sigma^t Y = \sigma^t Y
\end{align*}
\]

We can also solve the problem explicitly by writing out the full expressions:

\[
\begin{align*}
(58.1) & \quad \frac{d - 1}{\sin \theta} = Y \\
(59.1) & \quad \frac{d - 1}{\nabla} = \sigma^t Y
\end{align*}
\]

Yielding the solution

\[
\begin{align*}
(56.1) & \quad \nabla + \sigma^t Y = \sigma^t Y
\end{align*}
\]

… for sufficiently large \(u\). The limit \(Y\) must thus satisfy the iterative formula, i.e.,

\[
\begin{align*}
(59.1) & \quad \nabla \frac{d - 1}{\sin \theta} = \sigma^t Y
\end{align*}
\]

One does not have to write out the complete expression \(Y\) as a function of \(Y\) and

\[
\begin{align*}
(57.1) & \quad \nabla + u^t Y = 1^d + u^t Y
\end{align*}
\]

We therefore have

\[
\begin{align*}
(60.1) & \quad \theta \sin \phi \theta = \nabla
\end{align*}
\]

by which mass of the prism decreases by \(\theta \sin \phi \theta = d\) and its kinetic energy increases for this reason.

\[
\begin{align*}
(53.1) & \quad u^t Y = u^t Y
\end{align*}
\]

\[
\begin{align*}
(54.1) & \quad \theta \sin \phi \theta = \nabla
\end{align*}
\]

by which mass of the prism decreases by \(\theta \sin \phi \theta = d\) and its kinetic energy increases for this reason.
\[\phi_0 \approx \theta_0^0 \approx 6.28^0\]

That is,

\[\cos \theta = n - \{1 + \varepsilon (c/1 + V)^{1/1}\}\]

and obtain

\[\tan \theta = n \approx \left(\frac{1 + \varepsilon (c/1 + V)^{1/1}}{c/1 + V}\right)\]

To solve this we denote

\[1 < \theta \cos \varepsilon (c/1 + V) + \theta \sin (c/1 + V)\]

\[\theta \sin 30^0 \sin \phi - \theta \cos 30^0 \cos \phi < \theta \sin \phi\]

\[\phi_0^0 = \frac{\phi_1 - \phi_1}{\phi_1 - \phi_1} = V\]

We put in part (e) of the definite solution found in part (d) must be larger than the minimum value for continuation found in part (c). For the indefinite continuation the limit value of \(Y\) in part (d) must be larger than the

\[\phi_0^0 \approx \theta_0^0 \approx 6.28^0\]
| 2.0 | Answer: Minimum angle \( \theta = 6.28^\circ \) by equation (1.13). |
| 2.0 | Answer: Limit by \( \theta \) by equation (1.28). |
| 1.5 | Answer: \( l' = 12/1 = 1.2 \) by equation (1.12). |
| 1.0 | Answer: \( s = 12/1 = 12 \) by equation (1.12). |
| 3.5 | Answer: \( c = 12/1 = 12 \) by equation (1.12). |
Problem 2.1

Water under an ice cap

Problem text
The water flowing away can be assumed to have a temperature of 0°C. Subsequently, water is not in thermal equilibrium at the surface of the magma and hence flows away. Given these assumptions, the melting of the ice takes place in two steps. At first the centered above the center of the magma intrusion, such that the volume melted from the ice at any time is bounded by a constant surface exchange of heat in the process. The heat flow is assumed to have been primarily vertical. The time for the rise of the magma was short relative to the time for the melt. Assume that the ice only moved vertically. Also assume that the magma was completely molten.

As the ice cap moves, the shape of the surface of the ice cap changes and becomes more flat and hydrostatic equilibrium has been reached.

Plane 21: Cross section of an ice cap with a plane surface resulting on an inclined plane.
2.2

Solution

Based on the conservation of energy we have (2.2)

\[ p \cdot 1 \text{ year} = I \]

Place on a graph answer sheet, to scale, the shapes of the rock intrusion and of the area.

3. The total mass \( m \) of the ice produced and the mass \( m \) of water that flows

2. The height \( h \) of the intrusion.

1. The height \( H \) of the cap of the water cone formed under the ice cap, relative to the original bottom of the ice cap.

\[ h = x \]

\[ \theta = \frac{1}{3} h \]

\[ 0 = x \]

\[ 0 = \theta \]

\[ q = h \]

\[ x = 0 = \theta \]

\[ I \]

\[ 0 = \theta \]

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(3) $\nu d + \rho \eta \theta \delta \psi + \left(\tan \alpha - \rho \theta \phi \theta \psi \right)x \theta \eta \alpha \theta \psi = \nu d + \left(\nu \theta - \varepsilon \theta \right) \delta \theta \psi = d$

Therefore, at the bottom of the ice cap, where $\theta \psi = d$

\begin{align*}
(4) \quad \nu d + \varepsilon \theta \psi & = d \\
\end{align*}

Cap the pressure is given by:

Let $\nu a$ be the atmospheric pressure, taken to be constant. At a depth $z$ inside the ice

\begin{align*}
(5) \quad w_{z} = \frac{\nu a}{s \cdot 0.9 \cdot 10^{1}} = \frac{\nu d}{s \cdot 1 \cdot \text{year}} = P
\end{align*}

\begin{align*}
0 = x
\end{align*}

A \text{ vertical section through the mid-plane of a water-cone inside an ice cap.}

Surface: $\text{water, ice, ground, ice cap}$

Diagram 3. A \text{ vertical section through the mid-plane of a water-cone inside an ice cap.}$
14

Now process with the solution:

\[
\frac{\tan \theta}{d} = \frac{s}{d} - \phi
\]

where the minus sign is significant.

\[
\tan \theta = \frac{s}{d} \quad (0.10)
\]

\[
\frac{d}{\tan \theta} = \frac{s}{d} - \phi
\]

\[
\tan \theta = \frac{s}{d} \quad (0.12)
\]

\[
\frac{d}{\tan \theta} = \frac{s}{d} - \phi
\]

Therefore

\[
\frac{d}{\tan \theta} = \text{constant} = \phi
\]

\[
\text{constant} = d
\]

The figure is NOT drawn to scale.

\[
\text{Note that}
\]

Figure 2: A vertical and central cross section of a concave depression in a temperature ice cap. S: Surface; I: Ice cap; W: Water; M: Magna intrusion. S: Ice cap; G: Ground; I: Ice cap; W: Water. Note that the figure is NOT drawn to scale.
The heat balance gives

\[ 0 = \{\varepsilon \eta \varphi \varphi - (\Delta \nabla \psi + \psi \eta \eta \eta \} \varphi \psi = \frac{\varepsilon}{\varphi} \]

Following part (c). Thus, the required height of the top of the water cone is

\[ m_0 \times 1.1 = \eta \frac{\partial \varphi}{\partial \psi} = \varepsilon \eta + 1 \eta = H \]

The depth of the depression at the surface will be given by

\[ (\varepsilon \eta + 1 \eta) \frac{\partial \eta}{\partial \varphi} = \eta \]

The local height of the ice cone needed is

\[ \varepsilon \eta + 2 \eta + 1 \eta = \varepsilon \eta \]


The students are supposed to show this result in a graph.

The distance is

\[ x = 0.03 \text{ km} = 2 \text{ km} \]

\[ \tan \theta = \frac{\varepsilon}{\eta} \]

(a) The height of the surface will have the same readings as the height of the ice cone. According to (b), it will have

Since the ice adapts by vertical motion only, we see that the conical depression at the surface will have the same readings of 1.0 km as the ice cone. Accordingly to (b), we have

(b) The students are supposed to draw this line on a graph.
2.3 Grading scheme

Water flows.

The students are highly expected to plot the shapes of the rock intrusion and the

\[ H = \frac{\eta}{\rho} \frac{d}{d} = \frac{\eta}{\rho} \frac{d}{d} \frac{1}{\eta} = \frac{\eta}{\rho} \]

The mass of the water which flows away is

\[ H = \frac{\eta}{\rho} \frac{d}{d} \frac{1}{\eta} = \frac{\eta}{\rho} \]

The total mass of water formed is of course equal to the mass of the ice melted and is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \]

Inserting the equation (2.9) we can solve for \( \eta \).

This implies that the cone does not reach the surface of the ice cap. Inserting the

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \]

Therefore (using equation (2.10)) we obtain

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

where

\[ \eta = \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (v): Graph the

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (vi): The mass of water flowing away is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (vii): Total mass of water flowing away is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (viii): The pressure of intrusion in the rock intrusion is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (ix): The pressure of intrusion in the rock intrusion is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]

Answer (x): The pressure of intrusion in the rock intrusion is

\[ \frac{d}{d} \frac{1}{\eta} \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} + \frac{d}{d} \frac{1}{\eta} = \frac{d}{d} \]
Problem text
Figure 3.1: Radio emission from a source in our galaxy.
In the following numbered data:

given times by a radar and convert to seconds according to the given scale. This results
in another distance of the target center. We measure these quantities on the figure and the
time $\theta(t)$ of the echo center from the time as a function of time and $\theta(t)$ be
Let $\theta(t)$ be

\[ V = \frac{1}{a} \sqrt{\frac{g}{2} + \frac{1}{2}} - 1 = \theta' \]

and $\gamma$ of speed $\theta$ show that the unknown $\frac{\gamma}{a} = \theta'$ and $\theta$ can be expressed in terms of $\gamma_0$, $\gamma_1$, $\gamma_2$, and $\theta_0$. The estimated wavelength equation in the rest frame of the observer.

Draw the graph answer sheet. The condition of the maximum of the apparent perpendicularly incident region of the

\[ \phi \cdot \theta' < \frac{\gamma}{a} \]

\[ \text{The observer is at } O \text{ and the original position of the light source is at } A. \text{ The}\]

\[ \text{vector is } \vec{V}. \]
Due to the different distances to \( A \) and \( N \), and the finite speed of light, we have:

\[
\vec{V}_N \cdot \vec{g} = V_N \cdot g = \mathcal{N} \cdot \mathcal{g}
\]

Now let denote the difference in arrival times at the signal from \( A \) and \( N \):

\[
(3.7)
\]

We then have the point \( A' \), see Figure 3.4.

We consider the motion of the source during the time interval from the point \( A' \) to (b)

\[
(3.6) \quad \xi (20,0.83) \approx s/\mu s \cdot 1.8 \cdot 1.9 = \tau \gamma \alpha
\]

\[
(3.8) \quad \xi (200, 1.0) = s/\mu s \cdot 3.8 = 1.0
\]

(4.3) \quad \text{Figure 3.3: The angular distances} \( \theta \) and \( \gamma \) as functions of the time in days.

The uncertainty in the readings by the ruler is estimated to be \( \pm 0.2 \text{ mm} \), resulting in

\[
\begin{array}{c|c|c|c|c|c}
\hline
\text{days} & 0.0 & 0.3 & 0.6 & 0.9 & 1.2 \\
\hline
\text{mm} & 0.3 & 0.6 & 0.9 & 1.2 & 1.5 \\
\text{time} & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 \\
\text{days} & 0.6 & 0.9 & 1.2 & 1.5 & 1.8 \\
\hline
\end{array}
\]
\[ \begin{align*}
(4.3') & \quad \frac{(\phi \cos \theta + 1) H}{\phi \sin \theta} = \zeta_m \\
(3.3') & \quad \frac{(\phi \cos \theta - 1) H}{\phi \sin \theta} = \gamma_m
\end{align*} \]

Taking Eq. (3.2) then gives:

\[ \frac{(\phi \cos \theta - 1) H}{\phi \sin \theta} = \frac{H}{\gamma_m} = \zeta \]

The angular speed observed at O is \( \phi \) is

\[ \phi \theta \cos \theta = \frac{\gamma \theta}{x \theta} = \frac{\gamma}{x} \eta \]

where we have used that the real transverse speed in the reference frame of the observer

\[ \frac{\phi \cos \theta - 1}{\phi \sin \theta} \frac{H}{x \theta} = \frac{H \gamma \theta}{x \theta} = \frac{\gamma}{x} \eta \]

To this implies that an observer at \( \gamma \theta \) and find the apparent transverse speed of the source

\[ \frac{\phi \cos \theta - 1}{\phi \sin \theta} \frac{H}{\theta} = \frac{H \gamma \theta}{\theta} = \frac{\gamma}{\theta} \eta \]

and hence

\[ \frac{\phi \cos \theta - 1}{\phi \sin \theta} \approx \frac{\eta \theta}{\theta} \approx \frac{\gamma}{\theta} \eta \]

For small \( \gamma \theta \) such that we have

\[ \phi \cos \theta - 1 \approx \frac{\theta}{\theta} \approx \frac{\gamma}{\theta} \eta \]

\[ \phi \cos \theta - 1 \approx \frac{\theta}{\theta} \approx \frac{\gamma}{\theta} \eta \]

vector is \( \theta \).

\[ \phi \]

\[ \theta \]

\[ \gamma \theta \]

\[ \theta \]

\[ \gamma \theta \]

\[ \theta \]

\[ \gamma \theta \]

\[ \theta \]

\[ \gamma \theta \]

\[ \theta \]

\[ \gamma \theta \]
\[
\theta = 0.8920 \mp 0.08 = \theta
\]

\[
\phi = \tan^{-1}(0.20 \text{ rad}) = 0.3772 = \phi
\]

Inserting the values of \( \phi \) and \( \theta \), from part (a) and the given values of \( y \) and \( c \), we get:

\[
(12.3) \quad \frac{(\theta m + 1 m) \cos}{\theta m - 1 m} = \theta
\]

\[
(12.4) \quad (\phi \cos \theta + 1) \theta m = (\phi \cos \theta - 1) \theta m
\]

Dividing (12.3) by (12.6) gives in terms of \( \phi \) and the known quantities, the unknown quantities:

\[
(12.9) \quad \left( \frac{(\theta m - 1 m) \phi}{\theta m \theta m} \right) = \phi
\]

\[
(12.8) \quad \frac{(\theta m - 1 m) \phi}{\theta m \theta m} = \phi
\]

\[
\sin \phi \theta = \frac{1 m \theta m \phi \cos \theta}{\theta m \theta m}
\]

Subtracting (12.9) from (12.6) gives:

\[
(12.10) \quad \frac{y}{1 m \phi \sin \phi \theta} = 1 m \theta m (\phi \cos \theta + 1)
\]

\[
(12.11) \quad \frac{y}{\theta m \phi \sin \phi \theta} = \theta m 1 m (\phi \cos \theta - 1)
\]

The quantities \( \phi \) and \( \theta \) are given, but \( y \) and \( \theta m \) are to be determined as stated in

1. \( \phi - \theta = \phi \) and \( \phi = \theta \) = \( \phi \) \( \phi \) \( \phi \) \( \phi \) \( \phi \)

\( \phi \) = \( \phi \)

If the two objects have equal speeds but opposite velocities we have \( \phi \).
This is zero for \( \phi = \phi' \) where

\[
2 \left( \frac{\phi \cos \phi' - 1}{(\phi' - \phi \cos \phi')^2} \right) = \left( \frac{\phi p}{\tau \alpha} \right) \phi p
\]

To find the extrema of \( \frac{\tau \alpha}{p} \phi \) as a function of \( \phi' \) which is shown in Figure 3.6 as the curve bounding the shaded area where \( \phi' < \frac{\tau \alpha}{p} \).

This defines \( \phi' \) as a function of \( \phi' \) which is shown in Figure 3.6 as the curve bounding the shaded area where \( \phi' < \frac{\tau \alpha}{p} \).

\[
2 \left( \frac{\phi + \phi'}{2} \right) \sin \phi' = \left( \frac{\phi p}{\tau \alpha} \right) \phi p
\]

Let the mapping be defined by the equality sign in \( z' = \frac{\mu}{\nu} \).

We therefore take a closer look at the region where the solution for \( \phi' \) is

\[
\left[ \frac{z}{\mu}, 0 \right] \times \left( I, \frac{\nu}{\nu - I} \right] \ni (\phi', \phi)
\]

It is obvious that (3.32) can only be satisfied for \( \phi' \) can only have

\[
\left[ \frac{\nu}{\mu}, 0 \right] \times \left( I, 0 \right] \ni (\phi', \phi)
\]

The physically relevant region in the plane is

\[
\left( \frac{\nu}{\mu} + \phi \right) \sin \phi = (\phi) f < \phi'
\]

and hence (3.31) is satisfied if

\[
\frac{2 \phi}{I} \leq \frac{\phi + \phi'}{2} \sin \phi
\]

\( I \leq \left( \frac{\phi \sin \phi' + \frac{\phi}{\nu} \sin \phi}{\sin \phi} \right) \phi \sin \phi'
\]

\[
\phi \cos \phi' - 1 \leq \phi \sin \phi'
\]

\[
\phi \cos \phi' - 1 \leq \frac{\phi \cos \phi' - 1}{\phi \sin \phi'}
\]

Equation (3.31) is equivalent to

\( I \) larger than or equal to the speed of light \( I \) and only
We have the equations for relativistic Doppler shift:

\[ [\frac{\mathcal{L}}{\sqrt{\mathcal{L}^2}}] \times [\mathcal{L}] \in (\phi', \theta') \in \mathbb{R} \]

The time shown as a function of \( \phi' \) and \( \theta' \): the region of \( \phi' \) and \( \theta' \) that is valid.

\[
\phi' = \phi' + \alpha \phi' \cos \theta' - \delta \theta' \sin \phi'.
\]

\[
(3.39) \quad 0 \leq \theta' \rightarrow \theta'' = \lim_{\theta' \rightarrow \infty} \frac{\theta'}{\theta'}
\]

From this and (3.32) we see that

\[
(3.38) \quad \frac{\theta' - \theta''}{\theta''} = \lim_{\theta' \rightarrow \infty} \frac{\theta'}{\theta'}
\]

The apparent transverse speed is given by

\[
0 > \frac{\theta'(\theta' - 1)}{\theta'' \sin \theta'} = \lim_{\theta' \rightarrow \infty} \left( \frac{\theta'}{\theta'} \right) \frac{\theta'}{\theta'}
\]

At the extremum

\[
(3.36) \quad \left( \frac{\theta'(\theta' - 1)}{(\theta' - \theta' \cos \phi' \sin \theta')} \right) \theta' = \left( \frac{\theta'}{\theta'} \right) \frac{\theta'}{\theta'}
\]

To see that this is indeed a maximum, we differentiate (3.34) again and get:

\[
(3.35) \quad [\frac{\mathcal{L}}{\sqrt{\mathcal{L}^2}}] \in (\phi', \theta') = \lim_{\theta' \rightarrow \infty} \frac{\theta'}{\theta'}
\]

represents the constant function \( \theta' = 1 \). The upper left-hand corner shows where the function of \( \theta' \) and \( \theta' \) is valid. The green horizontal line and the curve in the region between the curves is a function of \( \theta' \). The curved surface is a function of \( \theta' \) and \( \theta' \). The figure shows the region between the curves.
\( \phi \) = \( \alpha \)

\[
\frac{1}{\beta} + \frac{1}{\gamma} - 1 = \frac{d}{1 - \lambda} = \epsilon
\]

\[
\lambda = (\epsilon - 1) \cdot \beta
\]

\[
\frac{\epsilon \beta - 1}{\gamma} = \frac{\alpha \beta}{\beta + \gamma} = d
\]

We add them to define an auxiliary ratio and solve for \( \epsilon \):

\[
\frac{\epsilon \beta - 1}{\phi \cos \beta \pm 1} = \frac{\alpha \beta}{\beta + \gamma}
\]