## Semi-final



5 problems: 20 points per problem

> | Use: |
| :--- |
| $g=10 \mathrm{~m} / \mathrm{s}^{2}$ |
| Volume of a sphere: $\frac{4}{3} \pi r^{3}$ |
| Surface area of a sphere: $4 \pi r^{2}$ |
| Surface area of a disc: $\pi r^{2}$ |
| Radius of the Earth: 6400 km |
| Density of water: $1000 \mathrm{~kg} / \mathrm{m}^{3}$ |
| Standard atmospheric pressure: $101,3 \mathrm{kPa}$ |
| Avogadro's Number: $6,02 \cdot 10^{23} \mathrm{~mol}^{-1}$ |
| Elementary electric charge: $1,60 \cdot 10^{-19} \mathrm{C}$ |
| Mass of the electron: $9,11 \cdot 10^{-31} \mathrm{~kg}$ |
| Ideal gas constant: $R=8.314 \mathrm{~J} \cdot \mathrm{~mol}^{-1} \cdot \mathrm{~K}^{-1}$ |
| Ideal gas law: $p V=n R T$ |
| Law of universal gravitation: $F=G \frac{m_{1} \cdot m_{2}}{r}$ |

## Problem 1

An earthquake occurring in the Mediterranean is detected by seismographs situated in laboratories in Barcelona ( Spain), London (England) and Cairo ( Egypt ). The earthquake produces both longitudinal waves ( $P$ waves ) and transverse waves ( $S$ waves). Each of the laboratories registers the $P$ waves before the $S$ waves. $P$ waves travel at a speed of $7 \mathrm{~km} / \mathrm{s}$ and $S$ waves travel at $3.5 \mathrm{~km} / \mathrm{s}$.

| Laboratory | P-waves | S-waves |
| :--- | :--- | :--- |
| Barcelona | $7 \mathrm{~h} 29,8 \mathrm{~min}$ | $7 \mathrm{~h} 31,7 \mathrm{~min}$ |
| London | $7 \mathrm{~h} 31,0 \mathrm{~min}$ | $7 \mathrm{~h} 33,7 \mathrm{~min}$ |
| Cairo | $7 \mathrm{~h} 32,8 \mathrm{~min}$ | $7 \mathrm{~h} 36,8 \mathrm{~min}$ |

a) The epicenter of an earthquake is the point at the Earth's surface from which the waves seem to originate. Calculate the distances between the epicenter and each of the three laboratories. Indicate the site of the earthquake on the map provided below.

b) The point $F$ in the Earth's crust where the earthquake begins (hypocenter or focus) is situated at a distance $h$ vertically under the epicentre $E$. The magnitude M of the earthquake measured at the epicenter is equal to 6 . The magnitude measured in S is equal to 5 .
The magnitude of an earthquake is given by

$$
\log E=4,8+\log M
$$

$E$ is the energy liberated in J.

The distance $d$ between the epicenter and $S$ is equal to 56 km .

The energy liberated at the focus is travelling as a spherical wave in all directions; hence the wavefronts are spherical.
Calculate the distance $h$.


Solution:

## Problem 2

In physics, the effects of gravitation are often compared to what we observe in an accelerating reference frame.
a) A person is standing in an elevator at rest. One of the side walls has a small hole T pierced through it. A laser pointer is placed in the elevator shaft in such a way that it shines a light beam horizontally through the hole leaving a visible dot on the opposite wall at point $A$. T and A are at the same height. The width of the elevator is $L$. The elevator abruptly starts accelerating upwards with an acceleration $a=g$. Find the point $B$ where the light hits the wall on the opposite side of $T$. The speed of light is $c=300000 \mathrm{~km} / \mathrm{s}$.


In the reference frame of the elevator, determine the expression for the angle $\alpha=\widehat{A T B}$ as a function of $g, c$ and $L$.
b) Light coming from a star which grazes the Sun's surface is deviated by its gravitational field. The deviation is very small. Assume the gravitational field only acts during a time $\frac{2 R}{c}$ which is the time it takes light to travel the distance of the diameter of the Sun.
Find an approximate expression for the deviation angle $\alpha$ as a function of $G$ (gravitational constant), $M$ (solar mass), $R$ (solar radius) and $c$ (speed of light).
Give an estimate for $\alpha$.
$G=6,67 \cdot 10^{-11} N^{2} \mathrm{~m}^{2} / \mathrm{kg}^{2}, M=2 \cdot 10^{30} \mathrm{~kg}, R=7 \cdot 10^{5} \mathrm{~km}$

$\square$
Name:
Problem 2

Solution:

## Problem 3

A frictionless cylinder of cross-sectional area S and height H contains air which can be trapped by a disc of mass $m$ that fits the cylinder tightly. The disc can move freely inside the cylinder without friction. The disc is dropped into the cylinder and stabilises at a height $H_{0}$. The cylinder is open to atmospheric pressure at one end.

a) What is the absolute pressure $p_{0}$ of the air in the cylinder when the disc has settled at the height $H_{0}$ ?
b) The disc is slightly displaced. When it is released it oscillates about its equilibrium position with an amplitude $x$. The system is kept at constant temperature during the duration of the oscillations and $x \ll H_{0}$. Find the period $T$ of the oscillations.
c) Are the oscillations harmonic i.e. is the restoring force proportional and opposite to the displacement?
$p_{a}$ is the normal atmospheric pressure. The air is considered to behave like an ideal gas.
Mathematical approximations:
$(1+y)^{n} \approx 1+n y \quad$ when $y \ll 1$
$y^{2}$ is negligible compared to $y$ when $y \ll 1$

## Solution :

## Problem 4

An elastic band with negligible mass is fixed between two plates kept at a fixed distance $L$ equal to 40 cm . The elastic band is behaving like a spring with a spring constant of $1.0 \mathrm{~N} / \mathrm{cm}$. Pulling the band vertically downwards at point $A$ displaces point $A$ downwards by $\Delta x$.

a) The unstretched length of the elastic band is equal to 40 cm . Calculate the distance $x$ of point $A$ from the upper plate to get the largest displacement of $A$ downwards for an applied force of $15 N$ and indicate the magnitude $\Delta x$ of the displacement.
b) The unstretched length of the elastic band is now much smaller than $L$. The elastic band is stretched between the two plates kept at a distance of 40 cm . Calculate the distance $x$ and the displacement $\Delta x$ of point $A$ for an applied force of 15 N in this case.

Solution:

## Problem 5

A group of 12 resistors is arranged along the edges of a cube as shown in the diagram below. The vertices of the cube are labeled $a-h$.


The resistance between each pair of vertices is as follows:

$$
\begin{gathered}
R_{a b}=R_{a c}=R_{a e}=3,0 \\
R_{c g}=R_{e f}=R_{b d}=8,0 \Omega \\
R_{c d}=R_{b f}=R_{e g}=12,0 \Omega \\
R_{d h}=R_{f h}=R_{g h}=1,0 \Omega
\end{gathered}
$$

What is the equivalent resistance between points $a$ and $h$ ?
$\square$
Name:

