Group Number: 2

Physics

Winter term 2021/22

Group Work

1 Momentum and Force. Fields of Force

1.1 Momentum and Force. Fields of Force

The so-called neutron stars have about the mass of our sun (ca. $2 \cdot 10^{30} kg$) and a typical diameter of about 20 km. Their mean mass density is roughly that of an atomic nucleus.

a). How big is the mean mass density?

b). According to Newton's law of gravitation, how heavy would a piece of weight with the mass of 1kg be on the surface of a neutron star?

c). How heavy would $1mm^3$ of neutron star matter be on earth and what diameter would an iron ball of the same mass have?

1.2 Coulomb interaction of two electrons

Sketch correctly to scale the course of the magnitude of the force with which two electrons repel each other at distances of $0,5 \cdot 10^{-10}$m to $5,0 \cdot 10^{-10}$m according to Coulomb's law.

$$[Q] = As \tag{1}$$

$$e = 1.6022 * 10^{-19} As \tag{2}$$

$$Q = n * e \tag{3}$$

$$Q_1 = Q_2 = e = 1.6022 * 10^{-19} As \tag{4}$$

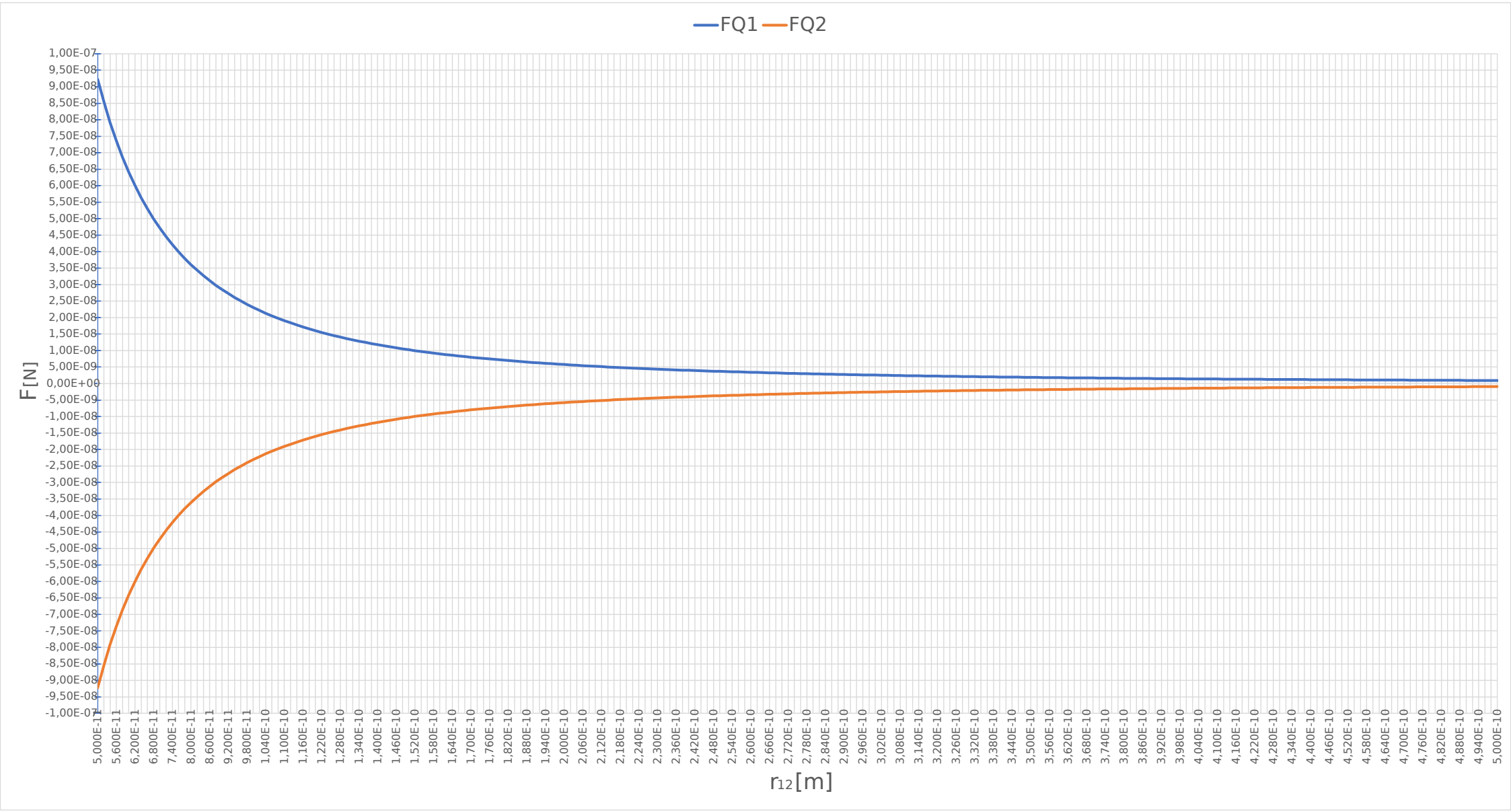
$$\epsilon = \epsilon_0 * \epsilon_r \tag{5}$$

$$\epsilon_0 = 8.854 * 10^{-12} \frac{As}{Vm} \tag{6}$$

$$\epsilon_r = 1(\epsilon_r \text{ for vaccuum}) \tag{7}$$

$$\vec{F_{Q1}} = \frac{1}{4 * \pi * \epsilon} * \frac{Q_1 * Q_2}{r^2} * \frac{\vec{r}_{12}}{|\vec{r}_{12}|} = -\vec{F_{Q2}} \tag{8}$$

See calculation of data points in appendix 3.1 Data table 1.2 (A2)


FQ1
FQ2
F[N]
r12[m]
1,00E-07
9,50E-08
9,00E-08
8,50E-08
8,00E-08
7,50E-08
7,00E-08
6,50E-08
6,00E-08
5,50E-08
5,00E-08
4,50E-08
4,00E-08
3,50E-08
3,00E-08
2,50E-08
2,00E-08
1,50E-08
1,00E-08
5,00E-09
0,00E+00
-5,00E-09
-1,00E-08
-1,50E-08
-2,00E-08
-2,50E-08
-3,00E-08
-3,50E-08
-4,00E-08
-4,50E-08
-5,00E-08
-5,50E-08
-6,00E-08
-6,50E-08
-7,00E-08
-7,50E-08
-8,00E-08
-8,50E-08
-9,00E-08
-9,50E-08
-1,00E-07
5,00E-11
5,60E-11
6,20E-11
6,80E-11
7,40E-11
8,00E-11
8,60E-11
9,20E-11
9,80E-11
1,04E-10
1,10E-10
1,16E-10
1,22E-10
1,28E-10
1,34E-10
1,40E-10
1,46E-10
1,52E-10
1,58E-10
1,64E-10
1,70E-10
1,76E-10
1,82E-10
1,88E-10
1,94E-10
2,00E-10
2,06E-10
2,12E-10
2,18E-10
2,24E-10
2,30E-10
2,36E-10
2,42E-10
2,48E-10
2,54E-10
2,60E-10
2,66E-10
2,72E-10
2,78E-10
2,84E-10
2,90E-10
2,96E-10
3,02E-10
3,08E-10
3,14E-10
3,20E-10
3,26E-10
3,32E-10
3,38E-10
3,44E-10
3,50E-10
3,56E-10
3,62E-10
3,68E-10
3,74E-10
3,80E-10
3,86E-10
3,92E-10
3,98E-10
4,04E-10
4,10E-10
4,16E-10
4,22E-10
4,28E-10
4,34E-10
4,40E-10
4,46E-10
4,52E-10
4,58E-10
4,64E-10
4,70E-10
4,76E-10
4,82E-10
4,88E-10
4,94E-10
5,00E-10

2 Work and Power. Energy. Heat and Temperature

2.1 train set

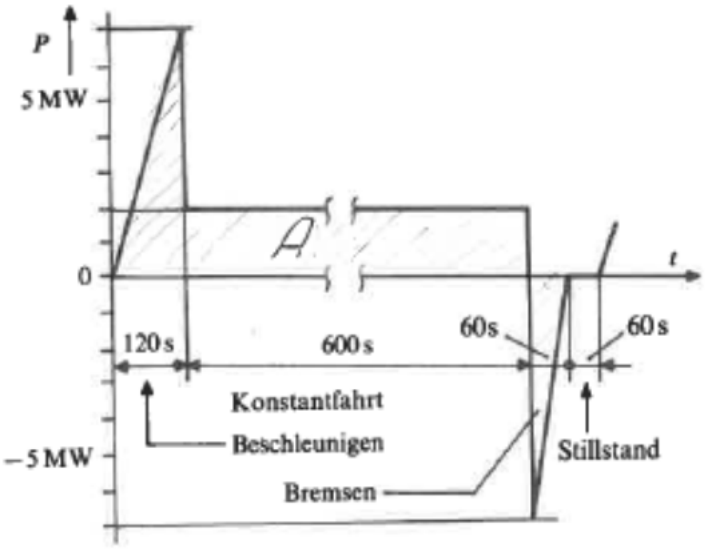
For example, the electric drive of a train set consumes the power shown in the figure below during a operational cycle (1 MW = 106 W).

a). What is the total electrical energy consumed during this operational cycle?

$$
\begin{aligned}
P_1 &= \tfrac{7MW \cdot\ 120s}{2} = 420\ MWs = 420\ MJ \\
P_2 &= 2\ MW * 600s = 1200\ MW = 1.2\ GJ \\
P_3 &= \tfrac{-7MW * 60s}{2} = -240\ MW \\
P_{total} &= P_1 + P_2 + P_3 = 420\ MJ + 1.2\ GJ - 240\ MJ = 1.38\ GJ
\end{aligned}
$$

b). What is the mean power consumed?

$$P_{mean} = \tfrac{P_{total}}{\Delta t} = \tfrac{1.38\ GJ}{\Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4} = \tfrac{1.38\ GWs}{120s + 600s + 60s + 60s} = 1.643\ MW$$



2.2 crash test facility

In a crash test facility, a vehicle including cuts m = 900 kg is accelerated uniformly via an electric linear motor through a distance s = 20 m with a constant force F = 5 kN.

a). How big is the necessary electrical energy in kWh if all losses are neglected?

b). How big is the final speed achieved? During the subsequent impact process, the vehicle is brought to a standstill within a distance of s = 80 cm.

c). What is the mean force that acts on a fictitious seated occupant, m1 = 80 kg?

2.3 Connected load of a flow heater

Suppose you want to design an electric water heater without a storage tank that heats a water flow of 0,1 l/s from 10 °C to 60 °C. What is the minimum required electrical connection power? (specific heat capacity of water c = 4,19 kJ/(kgK)).

$T_{in} = 10°C$
$T_{out} = 60°C$
$\Delta T = 50^{\circ}C \ = \ 50K$
$water \ flow \ = \ 0.1 \ l/s$
$m \ = \ 0.1kg$
$specific \ heat \ capacity \ of \ water \ c \ = \ 4.19kJ/(kgK)$
$total \ energy \ to \ heat \ up \ 0.1l \ water \ \Delta Q \ = \ c \ * \ m \ * \ \Delta T$
$minimum \ required \ electrical \ connection \ power \ [W] \ = \ kWh$

$Required \ energy \ to \ heat \ up \ 0.1 \ kg \ water \ from \ 10°C \ to \ 60°C$
$[\Delta Q] \ = \ K \ * \ kg \ * \ \frac{kJ}{kg \ * \ K} \ = \ kJ$
$\Delta Q \ = \ 50 \ * \ 0.1 \ * \ 4.19 \ = \ 20.95 \ kJ$

$Required \ connection \ power \ to \ heat \ up \ 0.1l/s \ water \ from \ 10°C \ to \ 60°C$
$[P] \ = \ W$
$P = 1000 \ * \ kJ \ / \ t_s \ (we \ need \ this \ energy \ every \ second \ to \ heat \ up \ the \ water \ constantly)$
$P \ = \ 1000 \ * \ 20.95 \ / \ 1 \ = \ 20950W \ = \ 20.95kW$

3.0 Appendix

3.1 Data table 1.2 (A2)

r [m]	F_{Q1} [N]	F_{Q2} [N]
5,000E-11	9,229E-08	-9,229E-08
5,200E-11	8,533E-08	-8,533E-08
5,400E-11	7,912E-08	-7,912E-08
5,600E-11	7,357E-08	-7,357E-08
5,800E-11	6,858E-08	-6,858E-08
6,000E-11	6,409E-08	-6,409E-08
6,200E-11	6,002E-08	-6,002E-08
6,400E-11	5,633E-08	-5,633E-08
6,600E-11	5,297E-08	-5,297E-08
6,800E-11	4,990E-08	-4,990E-08
7,000E-11	4,709E-08	-4,709E-08
7,200E-11	4,451E-08	-4,451E-08
7,400E-11	4,213E-08	-4,213E-08
7,600E-11	3,994E-08	-3,994E-08
7,800E-11	3,792E-08	-3,792E-08
8,000E-11	3,605E-08	-3,605E-08
8,200E-11	3,431E-08	-3,431E-08
8,400E-11	3,270E-08	-3,270E-08
8,600E-11	3,120E-08	-3,120E-08
8,800E-11	2,979E-08	-2,979E-08
9,000E-11	2,848E-08	-2,848E-08
9,200E-11	2,726E-08	-2,726E-08
9,400E-11	2,611E-08	-2,611E-08
9,600E-11	2,503E-08	-2,503E-08
9,800E-11	2,402E-08	-2,402E-08
1,000E-10	2,307E-08	-2,307E-08
1,020E-10	2,218E-08	-2,218E-08
1,040E-10	2,133E-08	-2,133E-08
1,060E-10	2,053E-08	-2,053E-08
1,080E-10	1,978E-08	-1,978E-08
1,100E-10	1,907E-08	-1,907E-08
1,120E-10	1,839E-08	-1,839E-08
1,140E-10	1,775E-08	-1,775E-08
1,160E-10	1,715E-08	-1,715E-08
1,180E-10	1,657E-08	-1,657E-08
1,200E-10	1,602E-08	-1,602E-08
1,220E-10	1,550E-08	-1,550E-08
1,240E-10	1,501E-08	-1,501E-08
1,260E-10	1,453E-08	-1,453E-08
1,280E-10	1,408E-08	-1,408E-08
1,300E-10	1,365E-08	-1,365E-08
1,320E-10	1,324E-08	-1,324E-08
1,340E-10	1,285E-08	-1,285E-08
1,360E-10	1,247E-08	-1,247E-08
1,380E-10	1,212E-08	-1,212E-08
1,400E-10	1,177E-08	-1,177E-08
1,420E-10	1,144E-08	-1,144E-08
1,440E-10	1,113E-08	-1,113E-08
1,460E-10	1,082E-08	-1,082E-08

r [m]	F_{Q1} [N]	F_{Q2} [N]
1,480E-10	1,053E-08	-1,053E-08
1,500E-10	1,025E-08	-1,025E-08
1,520E-10	9,986E-09	-9,986E-09
1,540E-10	9,728E-09	-9,728E-09
1,560E-10	9,481E-09	-9,481E-09
1,580E-10	9,242E-09	-9,242E-09
1,600E-10	9,012E-09	-9,012E-09
1,620E-10	8,791E-09	-8,791E-09
1,640E-10	8,578E-09	-8,578E-09
1,660E-10	8,373E-09	-8,373E-09
1,680E-10	8,175E-09	-8,175E-09
1,700E-10	7,983E-09	-7,983E-09
1,720E-10	7,799E-09	-7,799E-09
1,740E-10	7,621E-09	-7,621E-09
1,760E-10	7,448E-09	-7,448E-09
1,780E-10	7,282E-09	-7,282E-09
1,800E-10	7,121E-09	-7,121E-09
1,820E-10	6,965E-09	-6,965E-09
1,840E-10	6,815E-09	-6,815E-09
1,860E-10	6,669E-09	-6,669E-09
1,880E-10	6,528E-09	-6,528E-09
1,900E-10	6,391E-09	-6,391E-09
1,920E-10	6,259E-09	-6,259E-09
1,940E-10	6,130E-09	-6,130E-09
1,960E-10	6,006E-09	-6,006E-09
1,980E-10	5,885E-09	-5,885E-09
2,000E-10	5,768E-09	-5,768E-09
2,020E-10	5,654E-09	-5,654E-09
2,040E-10	5,544E-09	-5,544E-09
2,060E-10	5,437E-09	-5,437E-09
2,080E-10	5,333E-09	-5,333E-09
2,100E-10	5,232E-09	-5,232E-09
2,120E-10	5,133E-09	-5,133E-09
2,140E-10	5,038E-09	-5,038E-09
2,160E-10	4,945E-09	-4,945E-09
2,180E-10	4,855E-09	-4,855E-09
2,200E-10	4,767E-09	-4,767E-09
2,220E-10	4,681E-09	-4,681E-09
2,240E-10	4,598E-09	-4,598E-09
2,260E-10	4,517E-09	-4,517E-09
2,280E-10	4,438E-09	-4,438E-09
2,300E-10	4,361E-09	-4,361E-09
2,320E-10	4,287E-09	-4,287E-09
2,340E-10	4,214E-09	-4,214E-09
2,360E-10	4,142E-09	-4,142E-09
2,380E-10	4,073E-09	-4,073E-09
2,400E-10	4,006E-09	-4,006E-09
2,420E-10	3,940E-09	-3,940E-09
2,440E-10	3,875E-09	-3,875E-09

r [m]	F_{Q1} [N]	F_{Q2} [N]
2,460E-10	3,813E-09	-3,813E-09
2,480E-10	3,751E-09	-3,751E-09
2,500E-10	3,692E-09	-3,692E-09
2,520E-10	3,633E-09	-3,633E-09
2,540E-10	3,576E-09	-3,576E-09
2,560E-10	3,520E-09	-3,520E-09
2,580E-10	3,466E-09	-3,466E-09
2,600E-10	3,413E-09	-3,413E-09
2,620E-10	3,361E-09	-3,361E-09
2,640E-10	3,310E-09	-3,310E-09
2,660E-10	3,261E-09	-3,261E-09
2,680E-10	3,212E-09	-3,212E-09
2,700E-10	3,165E-09	-3,165E-09
2,720E-10	3,119E-09	-3,119E-09
2,740E-10	3,073E-09	-3,073E-09
2,760E-10	3,029E-09	-3,029E-09
2,780E-10	2,985E-09	-2,985E-09
2,800E-10	2,943E-09	-2,943E-09
2,820E-10	2,901E-09	-2,901E-09
2,840E-10	2,861E-09	-2,861E-09
2,860E-10	2,821E-09	-2,821E-09
2,880E-10	2,782E-09	-2,782E-09
2,900E-10	2,743E-09	-2,743E-09
2,920E-10	2,706E-09	-2,706E-09
2,940E-10	2,669E-09	-2,669E-09
2,960E-10	2,633E-09	-2,633E-09
2,980E-10	2,598E-09	-2,598E-09
3,000E-10	2,564E-09	-2,564E-09
3,020E-10	2,530E-09	-2,530E-09
3,040E-10	2,497E-09	-2,497E-09
3,060E-10	2,464E-09	-2,464E-09
3,080E-10	2,432E-09	-2,432E-09
3,100E-10	2,401E-09	-2,401E-09
3,120E-10	2,370E-09	-2,370E-09
3,140E-10	2,340E-09	-2,340E-09
3,160E-10	2,311E-09	-2,311E-09
3,180E-10	2,282E-09	-2,282E-09
3,200E-10	2,253E-09	-2,253E-09
3,220E-10	2,225E-09	-2,225E-09
3,240E-10	2,198E-09	-2,198E-09
3,260E-10	2,171E-09	-2,171E-09
3,280E-10	2,145E-09	-2,145E-09
3,300E-10	2,119E-09	-2,119E-09
3,320E-10	2,093E-09	-2,093E-09
3,340E-10	2,068E-09	-2,068E-09
3,360E-10	2,044E-09	-2,044E-09
3,380E-10	2,020E-09	-2,020E-09
3,400E-10	1,996E-09	-1,996E-09
3,420E-10	1,973E-09	-1,973E-09

r [m]	F_{Q1} [N]	F_{Q2} [N]
3,440E-10	1,950E-09	-1,950E-09
3,460E-10	1,927E-09	-1,927E-09
3,480E-10	1,905E-09	-1,905E-09
3,500E-10	1,883E-09	-1,883E-09
3,520E-10	1,862E-09	-1,862E-09
3,540E-10	1,841E-09	-1,841E-09
3,560E-10	1,820E-09	-1,820E-09
3,580E-10	1,800E-09	-1,800E-09
3,600E-10	1,780E-09	-1,780E-09
3,620E-10	1,761E-09	-1,761E-09
3,640E-10	1,741E-09	-1,741E-09
3,660E-10	1,722E-09	-1,722E-09
3,680E-10	1,704E-09	-1,704E-09
3,700E-10	1,685E-09	-1,685E-09
3,720E-10	1,667E-09	-1,667E-09
3,740E-10	1,649E-09	-1,649E-09
3,760E-10	1,632E-09	-1,632E-09
3,780E-10	1,615E-09	-1,615E-09
3,800E-10	1,598E-09	-1,598E-09
3,820E-10	1,581E-09	-1,581E-09
3,840E-10	1,565E-09	-1,565E-09
3,860E-10	1,548E-09	-1,548E-09
3,880E-10	1,533E-09	-1,533E-09
3,900E-10	1,517E-09	-1,517E-09
3,920E-10	1,501E-09	-1,501E-09
3,940E-10	1,486E-09	-1,486E-09
3,960E-10	1,471E-09	-1,471E-09
3,980E-10	1,457E-09	-1,457E-09
4,000E-10	1,442E-09	-1,442E-09
4,020E-10	1,428E-09	-1,428E-09
4,040E-10	1,414E-09	-1,414E-09
4,060E-10	1,400E-09	-1,400E-09
4,080E-10	1,386E-09	-1,386E-09
4,100E-10	1,373E-09	-1,373E-09
4,120E-10	1,359E-09	-1,359E-09
4,140E-10	1,346E-09	-1,346E-09
4,160E-10	1,333E-09	-1,333E-09
4,180E-10	1,320E-09	-1,320E-09
4,200E-10	1,308E-09	-1,308E-09
4,220E-10	1,296E-09	-1,296E-09
4,240E-10	1,283E-09	-1,283E-09
4,260E-10	1,271E-09	-1,271E-09
4,280E-10	1,259E-09	-1,259E-09
4,300E-10	1,248E-09	-1,248E-09
4,320E-10	1,236E-09	-1,236E-09
4,340E-10	1,225E-09	-1,225E-09
4,360E-10	1,214E-09	-1,214E-09
4,380E-10	1,203E-09	-1,203E-09
4,400E-10	1,192E-09	-1,192E-09

r [m]	F_{Q1} [N]	F_{Q2} [N]
4,420E-10	1,181E-09	-1,181E-09
4,440E-10	1,170E-09	-1,170E-09
4,460E-10	1,160E-09	-1,160E-09
4,480E-10	1,150E-09	-1,150E-09
4,500E-10	1,139E-09	-1,139E-09
4,520E-10	1,129E-09	-1,129E-09
4,540E-10	1,119E-09	-1,119E-09
4,560E-10	1,110E-09	-1,110E-09
4,580E-10	1,100E-09	-1,100E-09
4,600E-10	1,090E-09	-1,090E-09
4,620E-10	1,081E-09	-1,081E-09
4,640E-10	1,072E-09	-1,072E-09
4,660E-10	1,062E-09	-1,062E-09
4,680E-10	1,053E-09	-1,053E-09
4,700E-10	1,044E-09	-1,044E-09
4,720E-10	1,036E-09	-1,036E-09
4,740E-10	1,027E-09	-1,027E-09
4,760E-10	1,018E-09	-1,018E-09
4,780E-10	1,010E-09	-1,010E-09
4,800E-10	1,001E-09	-1,001E-09
4,820E-10	9,931E-10	-9,931E-10
4,840E-10	9,849E-10	-9,849E-10
4,860E-10	9,768E-10	-9,768E-10
4,880E-10	9,688E-10	-9,688E-10
4,900E-10	9,609E-10	-9,609E-10
4,920E-10	9,531E-10	-9,531E-10
4,940E-10	9,454E-10	-9,454E-10
4,960E-10	9,378E-10	-9,378E-10
4,980E-10	9,303E-10	-9,303E-10
5,000E-10	9,229E-10	-9,229E-10