**Problem T1. Main sequence stars (11 points)****Part A. Lifetime of Sun (3 points)**

i. (0.7 pts) The total radiation power of the Sun (expression and value in watts)

ii. (0.5 pts) Proof that the energy released by such a fusion of four protons is  $W_0 = 24 \text{ MeV}$

iii. (0.5 pts) Energy carried away from Sun by photons and neutrinos per each fusion of four protons (expression and value)

iv. (1.3 pts) An estimate for the total lifetime of the Sun (expression and value)

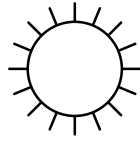
**Part B. Mass-luminosity relationship of stars (4.5 points)**

i. (0.4 pts) Free fall acceleration at point  $Q$  (expression)

ii. (0.4 pts) Free fall acceleration at point  $Q$  (expression)

iii. (0.4 pts) Gravity force acting on a piece of the spherical layer (expression)

iv. (0.4 pts) Core pressure  $p_c$  (expression)



v. (1 pt)  $p_c$  expressed in terms of  $R_0$ ,  $M$ , and  $T_c$ :

vi. (0.4 pts)  $R_0$  expressed in terms of  $M$  and  $T_c$ :

vii. (1.5 pts) Assuming  $P \propto M^\gamma$ , expression for the exponent  $\gamma =$

**Part C. Proton-proton fusion chain (3.5 points)**

i. (1.5 pts) Expression in terms of fundamental constants and value for the dimensionless combination  $\alpha^{-1}$

ii. (1 pt) Estimate for the fusion temperature  $T'$  based on classical thermodynamics (expression and value)

iii. (1 pt) The tunnelling probability for the proton-proton fusion reaction (expression)



**Problem T2. Water tube (8 points)**

i. (0.5 pts) Expression and value for  $p_P - p_Q$

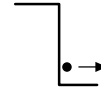
ii. (1.5 pts) Sketch of the tube with all the forces; expressions and magnitudes for these forces

iii. (1.2 pts) Expressions and values of the pressures  $p_P$  and  $p_Q$

iv. (0.8 pts) Expression and value of the tension force  $T$  in the steel bar

v. (1 pt) Why does the tube jump: a qualitative explanation

vi. (3 pts) The duration  $\tau$  (expression and value) during which the tube remains standing



**Problem T3. Accelerating shock wave (11 points)**

i. (1 pt) The velocity components  $v'_x$ ,  $v'_y$ ,  $v'_z$  of the electron after being hit by the shock wave

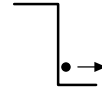
ii. (1 pt) A qualitative sketch of the trajectory drawn by the electron (at least  $t = \frac{\pi m}{Be}$ )

iii. (0.5 pts) The curvature radius of the electron's trajectory immediately after its first collision with the shock wave

iv. (1 pt) An equation for determining the time the second impact  $t_2$ , and a numerically obtained expression for  $t_2$

v. (0.5 pts) An expression for the average  $x$ -directional velocity  $v_x$  of the electron

vi. (1.5 pts) Proof that  $v_y + kx = \text{const}$ , and an expression for  $k$



vii. (1 pt) An expression for the average  $y$ -directional acceleration  $a_y$  of the electron

viii. (1 pt) A sketch for the electron's *phase trajectory*

ix. (1.5 pts) An expression for the total kinetic energy  $W_f$  of the electron when it falls behind the shock wave

x. (2 pts) By which relativistic energies of the electron will it fall behind the shock wave