1a.

- 1a^{18}F -> ^{18}O + e^+ + neutrino.
- Q = [$m_A(^{18}F)$ - $m_A(^{18}O)$ - 2*m_e]*c^2, where m_A is atomic mass.
- Q = 0.634 MeV.
- Electron capture, because Q(EC) -Q(beta+) > 0 always.

1b

- 18F is odd-odd nucleus, cannot be predicted from shell model.
- 18O is even-even nucleus, has 0+.
- $\Delta\pi$ = no -> L = 0,2.., $|\Delta I| = 1 \leq |\mathbf{L+S}|$
- Allowed transition of pure Gamow-Teller type.

2a

- Drawing of cyclotron and description of how it works.
- Cyclotron frequency: $f = \frac{qB}{2\pi m}$, q = charge of particle, B is strength of magnetic field, m is mass of particle.
- Kinetic energy of the proton: $T = \frac{(qBR)^2}{2m}$, R = radius of cyclotron.
- B = 1.0 Tesla.

2b

- Reaction: ^{18}O + p -> ^{18}F + n
- Energy conservation (subscript N means nuclear masses):
  - $[m_N(^{18}O)+m_p]c^2 + T_p + T_O = [m_N(^{18}F)+m_n]c^2 + T_n + T_F$
- Rewritten in terms of Q:
  - $T_p + T_O = T_n + T_F - Q$
  - $Q = [m_A(^{18}O) + m_p - m_A(^{18}F) - m_n + m_e]\, c^2$
  - Q = -2.43 MeV.
- Reaction energy (T_R) calculated in the laboratory frame is the kinetic energy of the projectile minus the kinetic energy of the CM. To find this one must determine the velocity of the CM: $V_{CM} = m_p v_p/(m_p+m_O)$
- $T_R = T_p - T_{CM} = ½ m_p v_p^2[1- m_p/(m_p+m_O)]$.

2c

- Semi-classical cross section: $\sigma = \pi[R + \lambda/2\pi]^2$, R = $R_0(1+18^{1/3})$ = 4.34 fm.
- $\lambda/2\pi$ = 0.83 fm.
- $\sigma =$ 0.84 b.
- Coulomb potential energy: B = 2.65 MeV.
- B is higher than Q.
- Hard sphere classical cross section with Coulomb repulsion:
  - $\sigma = \pi R^2(1 - B/T)$
  - $B/T =$ 0.09, cross section reduced by 9 %.

3

SEE = positron dose + annihilation photons doses.
Mass is not given, we choose m = 70 kg.

Positron emission:

Average energy = Q/3
yield = 1
absorbed fraction = 1
Radiation weight = 1
SEE(beta+) = 634/3 keV / 70 kg = 4.84 10^{-16} Sv

Annihilation photons (x2)
Average energy: 511 keV
yield = 1
Absorbed fraction is not given, so student must make a suggestion for this. A worst case calculation would be to use 1, more realistically somewhere in the range 0.3-0.5 (here we use 0.4).
Radiation weight = 1.
SEE(annihilation photons) = 0.4*2*511keV/70 kg = 9.36 10^{-16} Sv

Committed effective dose is given by SEE* number of disintegrations in the body over 50 years. Here halflife << 50 years, so:
$N_{dis} = \int_0^\infty A_0 exp(-\lambda t)dt \; = \; A_0/\lambda$ = 3.77 10^{12}

e(50) = 3.77 10^{12} *(4.84 10^{-16} +9.36 10^{-16}) Sv = 5.35 mSv

Annual dose limit is 1 mSv for the general public, so a PET exam gives more than 5 times that.

4a
Principles of PET imaging:

- beta+ emission, followed by annihilation and 2x 511 keV photon emission.
- Photons travel in nearly oppsite directions.
- Coincident detection of both photons enable the establishment of the socalled line of response LOR (line in space along which the aniihilation must have taken place).
- Detector ring positioned around subject will detect many LOR over a given acquisition time.
- Image Reconstruction can be performed in principally the same manner as for CT by filtered back projection.

Possible advantages:

- Better geometrical efficiency (no need for collimator as in the Gamma Camera).
- Biologically important elements have beta+ active isotopes (O, F, C N).

4b.
Interaction processes (should include a desciption of each process):

- Photo-electric effect
- Compton scattering
- NOT pair-production due to low energy.

Photo-electrons created in the PMT: N = 511 keV * 38000 photons/MeV *0.2 *0.9 = 3495

Energy-resolution = 2.355*100/sqrt(N) = 4.0 %

5a.

Momentum transfer analysis:

- **Δp** = Force integrated over time.
- No net Δp_x-component.
- Calculation of Δp_y-component gives: $\Delta py = \frac{Ze^2}{4\pi\varepsilon_0}\frac{2}{bV}$
- b is the impact parameter, V is the velocity of the heavy charged particle.
- Z is the charge of the particle, m is the mass.

5b

The Bragg peak is the peak in the energy transfer to the tissue dE/dx for an incoming heavy charged particle, located just before the particle comes to rest. From the above equation it can be seen that the energy transfer per collision is proportional to 1/E, so the lower the particle energy, the higher the energy transfer. As the energy goes to zero, this function will not be valid any more, and the energy transfer will be reduced to zero. The overall behaviour is a peak located just before the particle comes to rest.

The Bragg-peak is interesting for radiation therapy because of the low dose in front of the tumor plus the steep fall-off after the Bragg peak, compared to photon radiation therapy which delivers a smooth mono-exponentially decreasing dose-profile. It will potentially give much lower radiation dose to the healthy tissue.