Problem 1:
An example of a daily-used control system is the toilet flushing device connected to a water tank. A toilet flushing system is illustrated as seen below in Figure 1:

Figure 1: Toilet Flushing System
The control objective for the system is to fill the tank again after flushing until a desired water level is reached and then maintain that level.

a) Determine the type (OL or CL) of the overall control system.
b) Identify the basic control system components such as plant, controller, actuator, sensor, etc.
c) Describe the control process for this flushing system.
d) Draw a descriptive block diagram that represents this control system.

Problem 2:

All human beings have experienced a fever (body temperature) increase associated with an illness. Fever is the outcome governed by the thermostatic controller of the body. The increased activity of the hostile microorganisms triggers the central nervous system to command an increase in the set point (i.e., reference input) of the thermostat, because it happens that the immune response of the body can be strengthened at a higher temperature.

a) Identify the relevant inputs and outputs with their appropriate descriptions.
b) Identify the basic control system components such as plant, controller, actuator, sensor, etc.
c) Draw a descriptive block diagram of the temperature control system of the body and explain why and how a drug such as aspirin may lower the fever as a process of this system.
**Problem 3:**
An inertial load (i.e., a rotating mass) driven by an electric motor is a typical plant of a mechanical control system. A simplified schematic drawing of a DC motor is shown below in Figure 2.

![Simplified schematic drawing of a DC motor](image)

**Figure 2:** Simplified schematic drawing of a DC motor

The given DC motor drives an inertia $J_L$, which is supported by a bearing with viscous friction coefficient $b_L$. The rotor inertia $J_M$ of the DC motor is lumped with $J_L$ so that the total effective inertia becomes $J_{LM} = J_L + J_M$. Similarly, the friction in the motor with coefficient $b_M$ is added to the bearing friction leading to an effective coefficient $b_{LM} = b_L + b_M$.

The armature winding is placed within a uniform magnetic field of flux density $B$. Note that only one turn of the winding is shown in the figure for the sake of simplicity.

The resistance of the armature winding is $R$ and its inductance is $L$. When the input voltage $V(t)$ is applied to the DC motor, the current $i(t)$ flows in the armature winding.
Hence, as a current-carrying conductor within a magnetic field, the armature winding induces a force couple \( \{F_e(t), -F_e(t)\} \) exerted on its top and bottom sections as illustrated in the figure.

The value of \( F_e(t) \) is given below by Equation (1), where \( l \) is the length of the armature coil:

\[
F_e(t) = lBi(t)
\]  

(1)

Since the winding is free to rotate around its longitudinal axis, the magnetic force couple \( \{F_e(t), -F_e(t)\} \) produces the torque \( T_e(t) \). On the other hand, assuming that there are \( N \) turns of the armature winding, the total induced torque exerted on the armature winding is expressed below as Equation (2):

\[
T_e(t) = 2NrF_e(t)
\]  

(2)

When the armature winding starts to rotate within the magnetic field, a voltage \( V_i(t) \) is induced between its terminals. Taking into account the \( N \) turns and the two sections of each turn of the armature winding, the total induced voltage becomes expressed as given below by Equation (3):

\[
V_i(t) = 2NrBl\omega(t)
\]  

(3)

For the remaining electrical part of the system, the corresponding equations of the resistance and inductance can be written respectively as follows:

\[
V_R(t) = Ri(t)
\]  

(4)

\[
V_L(t) = L \frac{d[i(t)]}{dt}
\]  

(5)

According to the Kirchhoff’s voltage law, the following additional equation can be written:

\[
V(t) - V_R(t) - V_L(t) - V_i(t) = 0
\]  

(6)

As for the mechanical part of the system, the elemental equation of the combined inertia is written as

\[
T_e(t) - T_b(t) = JLM \frac{d\omega(t)}{dt}
\]  

(7)

In Equation (7), the elemental equation for the total frictional torque is:

\[
T_b(t) = b_{LM} \omega(t)
\]  

(8)
a) Identify the distinct unknown variables in the system and check whether the number of the unknown variables is equal to the number of the equations.

b) For the selected output $\omega(t)$, the input-output relationship can be written as follows in the s-domain:

$$\Omega(s) = G_{\Omega V}(s)V(s)$$

Determine the transfer function $G_{\Omega V}(s)$. Express it as an orderly written ratio of two polynomials.

c) From the s-domain input-output equation obtained in Part (b), obtain the t-domain input-output equation (i.e., the differential equation) between the output $\omega(t)$ and the input $V(t)$.  