Part	Criteria	Max	Points
a.1	Realizing that the velocity is constant	1.0	
a.2	Realizing that the droplet temperature during melting equals 0 °C	1.0	
a.3	Using Newton's cooling law and realizing that proportionality factor is constant	1.0	
a.4	Expressing heat by area and equating it with latent heat	1.0	
a.5	Determining the areas in the graphs	0.5	
a.6	Calculating the mass fraction	0.5	
	Subtotal part a.	**5.0**	
b.1	Arguing that the temperature of the droplet closely follows the temperature profile (explicit or implicit) *(0.5 for making use of this fact, 0.5 for motivating it)*	1.0	
b.2	Formulating differential equation for the (relative) droplet temperature	1.0	
b.3	Finding solution for (relative) temperature	1.0	
b.4	Determining relevant parameter in solution from previous results	0.5	
b.5	Realizing that exponential part is negligible at ground level	1.0	
b.6	Giving numerical result for droplet temperature	0.5	
	Subtotal part b.	**5.0**	

Details:

- Part b.: If students take the final temperature as equal to atmospheric temperature at ground without proper derivation they are awarded 1.5 point at maximum for part b.
- Part b.: Alternatively to b.2-b.5 students can also determine the change rate of droplet temperature with height, realize that this is much higher (for given temperatures) than the change rate of atmospheric temperature and from that argument that it is sufficient to look at the limiting case where the rate change of droplet and atmospheric temperature equal. This should also be awarded full marks.

General rules:

- **Follow the marking scheme!** Be consistent and generous.
- Make sure to look at all the scanned pages.
- Make notes for moderation (preferably in pdfs or alternatively on paper).
- Propagating errors: students are penalised *only* at the point of the original mistake, unless the result has wrong dimensions or other obviously physically wrong nature.
- All equations correct, numerical answer is wrong from calculation error: **-0.1** unless answer is clearly physically unreasonable.

Criteria	Max	Points
States that the work of the magnetic force and the force of static friction is zero	0.5	
Concludes that the speed (i.e. the magnitude of velocity) of the center of the ball is constant.	0.5	
Realizes that the force of static friction is perpendicular to the velocity. If the reasoning is physically wrong, 0 p.	0.5	
Concludes that the trajectory is circular.	0.5	
By using the condition of pure rolling derives kinematic relation between the horizontal (ω), vertical (Ω) components of the angular velocity and v. (0.5 p+0.5 p)	1.0	
Proves that the net Lorentz force is QvB. (No marks for the formula without proof.)	0.5	
Writes down Newton's second law in radial direction correctly. If either the Lorentz force or the frictional force is missing 0 p.	0.5	
Writes down an expression for the horizontal component of the angular momentum L.	0.5	
Realizes that the horizontal component of L precesses with angular velocity Ω	1.0	
Writes down equation relating the rate of change of L and the net torque. If either the torque of the friction or torque of magnetic field is missing, 0 p. If it does not use vectors, 0 p.	1.0	
Derives a relationship between the angular momentum of the ball and its magnetic moment. In case of a missing factor 1.5 p, in case of dimensional error 0.5 p, in case of physically wrong result (i.e. the torque is zero) or physically wrong reasoning 0 p.	2.0	
Writes down an expression for the torque of the magnetic forces ($\vec{\tau}_B = \vec{\mu} \times \vec{B}$ or equivalent expression)	0.5	
Writes down an equation for the torque of the static friction	0.5	
Solves the physically correct equations of motion and the kinematic equations and obtains expression for either Ω or the radius r of the trajectory. If vectors were not used, 0 p.	0.5	
Total	**10.0**	

Criteria	**Max**	**Points**
Realizing that the envelope is parabola	1.0	
Realizing that focus point of parabola is origin (or giving correct algebraic equation for the envelope)	1.0	
Realizing that each trajectory must touch envelope	1.0	
Realizing that touching point is at $y \geq 0$	1.0	
Realizing that at least one point of curve must lie on envelope	1.0	
Option A:		
Realizing that at this point water curve is tangent to envelope	1.0	
Understanding geometric property at this point from reflective behaviour	1.0	
Option B:		
Realizing that the point at the envelope has the largest value of $y + \sqrt{x^2 + y^2}$	2.0	
Finding the position of the point P at the envelope with reasonable accuracy	1.0	
Finding height of topmost point of parabola	1.0	
Determining velocity as $v = y_P + \sqrt{x_P^2 + y_P^2} \approx 12\,\mathrm{m\,s^{-1}}$	1.0	
Total	**10.0**	

Alternative approach	**Max**	**Points**
Find lower bound $v > \sqrt{g \cdot 11.5\,\mathrm{m}}$	2.0	
Alternative lower bound $v > \sqrt{2g \cdot 4.9\,\mathrm{m}}$	1.0	
Find upper bound $v < \sqrt{4g \cdot 4.9\,\mathrm{m}}$	2.0	
Improving lower bound correctly by using $y = 2.6\,\mathrm{m}$ at $x = 11.5\,\mathrm{m}$	1.0	
Improving upper bound in a similar way	1.0	
Considering different points to show that $v \geq 11.8\,\mathrm{m/s}$	1.0	
Considering different points to show that $v \geq 11.9\,\mathrm{m/s}$	1.0	
Considering different points to show that $v \leq 12.2\,\mathrm{m/s}$	1.0	
Considering different points to show that $v \leq 12.1\,\mathrm{m/s}$	1.0	
Total	**10.0**	

If contestant considers envelope of trajectories, the first scheme is applied. If he/she obtains a formula for the minimal speed to reach the given point as $v = \sqrt{g(y + \sqrt{x^2 + y^2})}$ without mentioning the envelope, and finds a maximal value of this expression (maximized over the water curve), the second alternative scheme is applied. In that case, this expression provides only a lower bound for v and upper bound would be also needed. If the upper bound is not found, but the obtained result (v around $12.0\,\mathrm{m/s}$) is presented as if an exact answer, the contestant is penalized with 0.5 pts for not realizing that only a lower bound has been found.